

JOURNAL OF THE IRON AND STEEL INSTITUTE

4 GROSVENOR GARDENS · LONDON · S.W.1

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VOL. 155

PART 4

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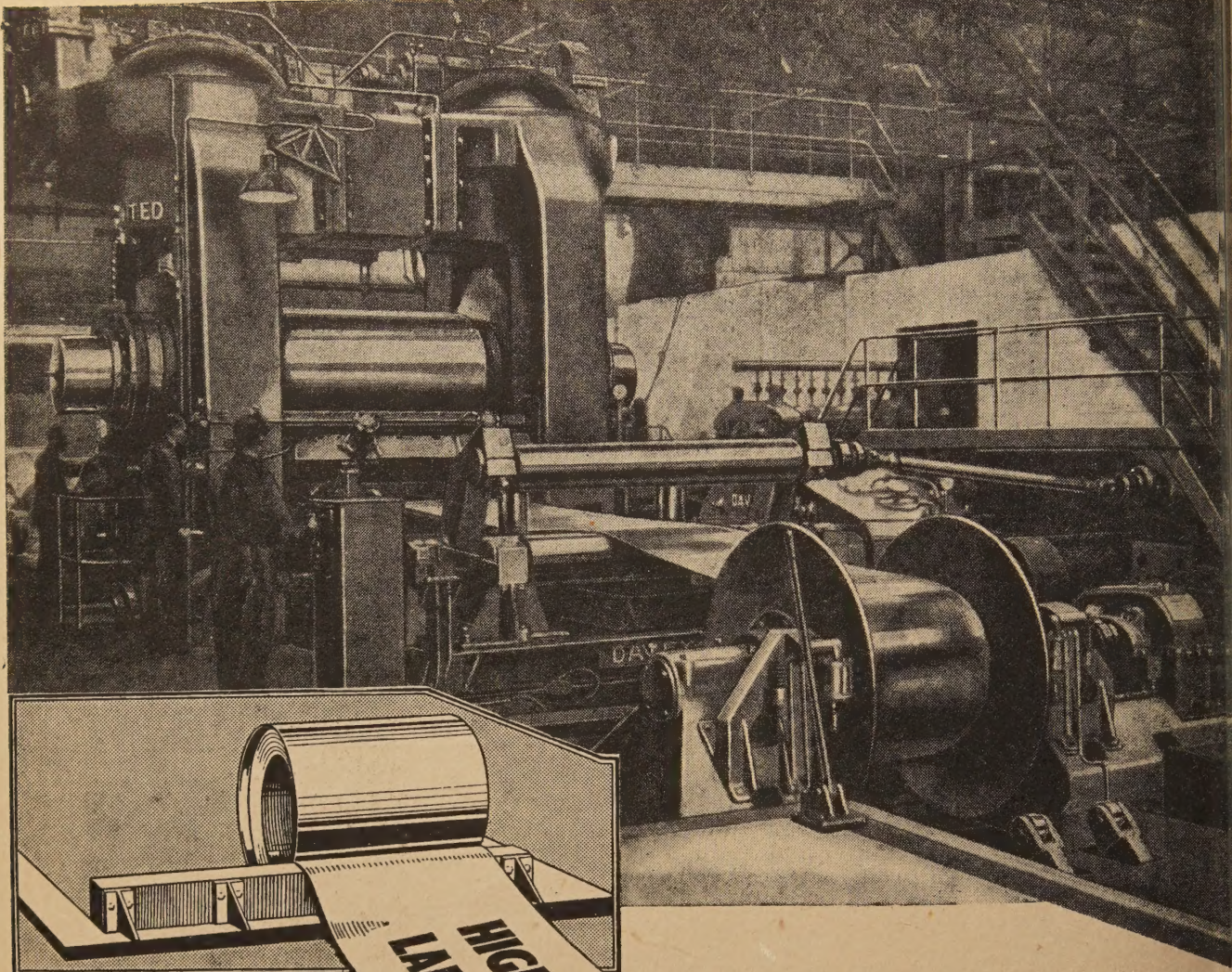
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News and Abstracts



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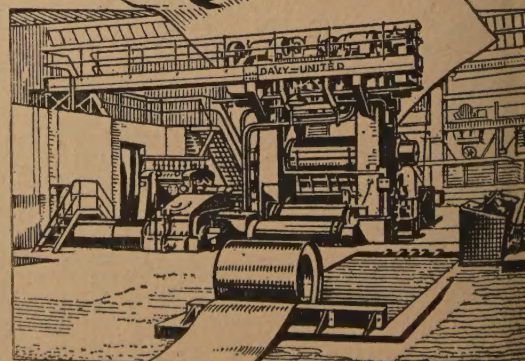
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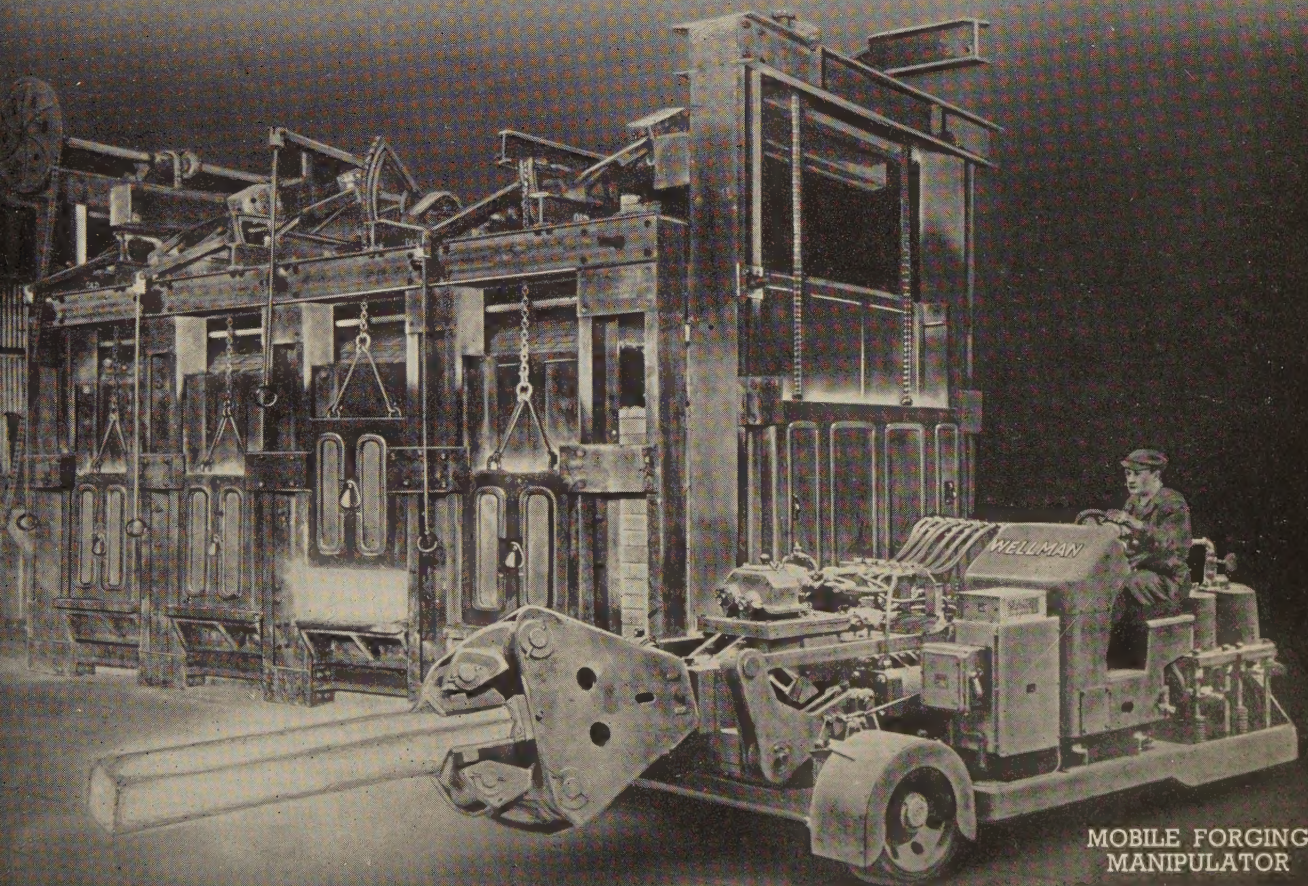
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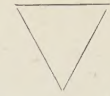
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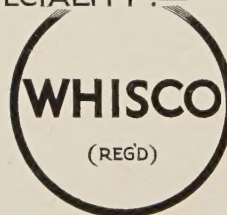
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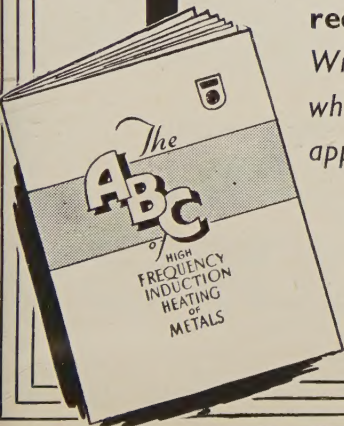


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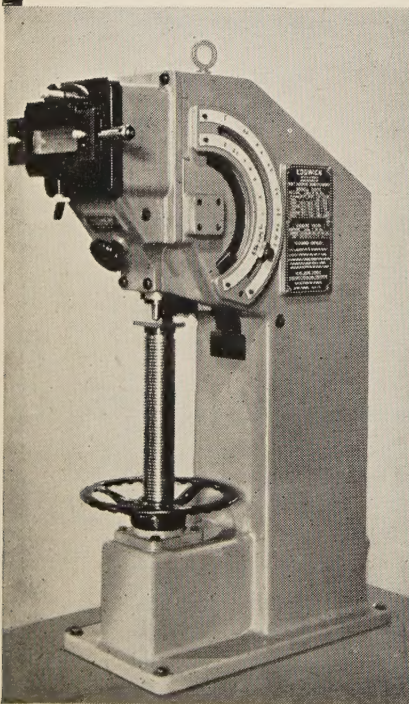
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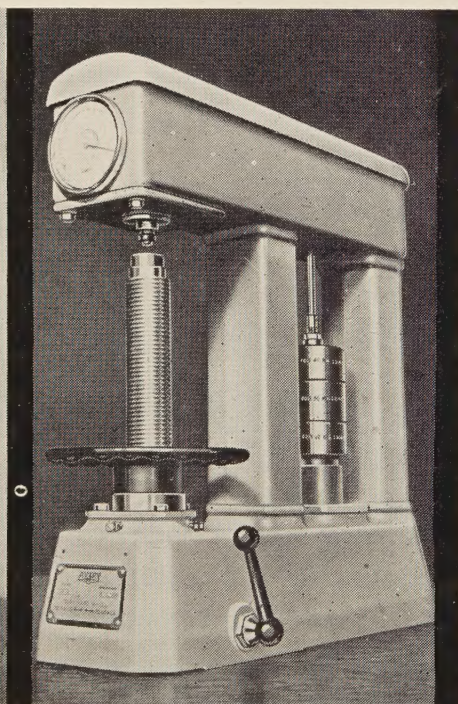
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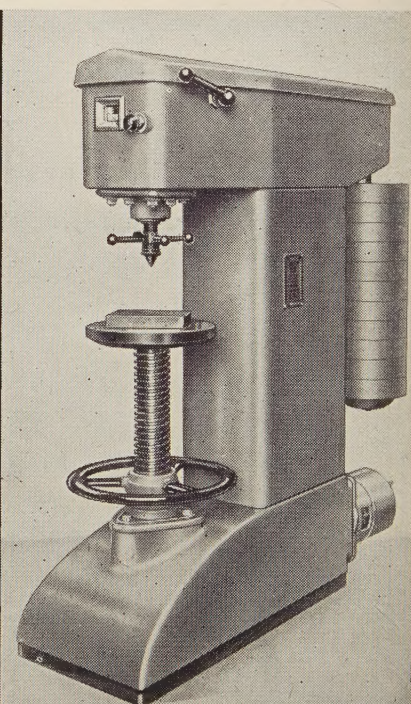
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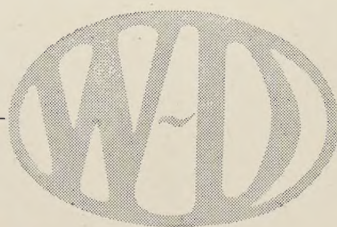
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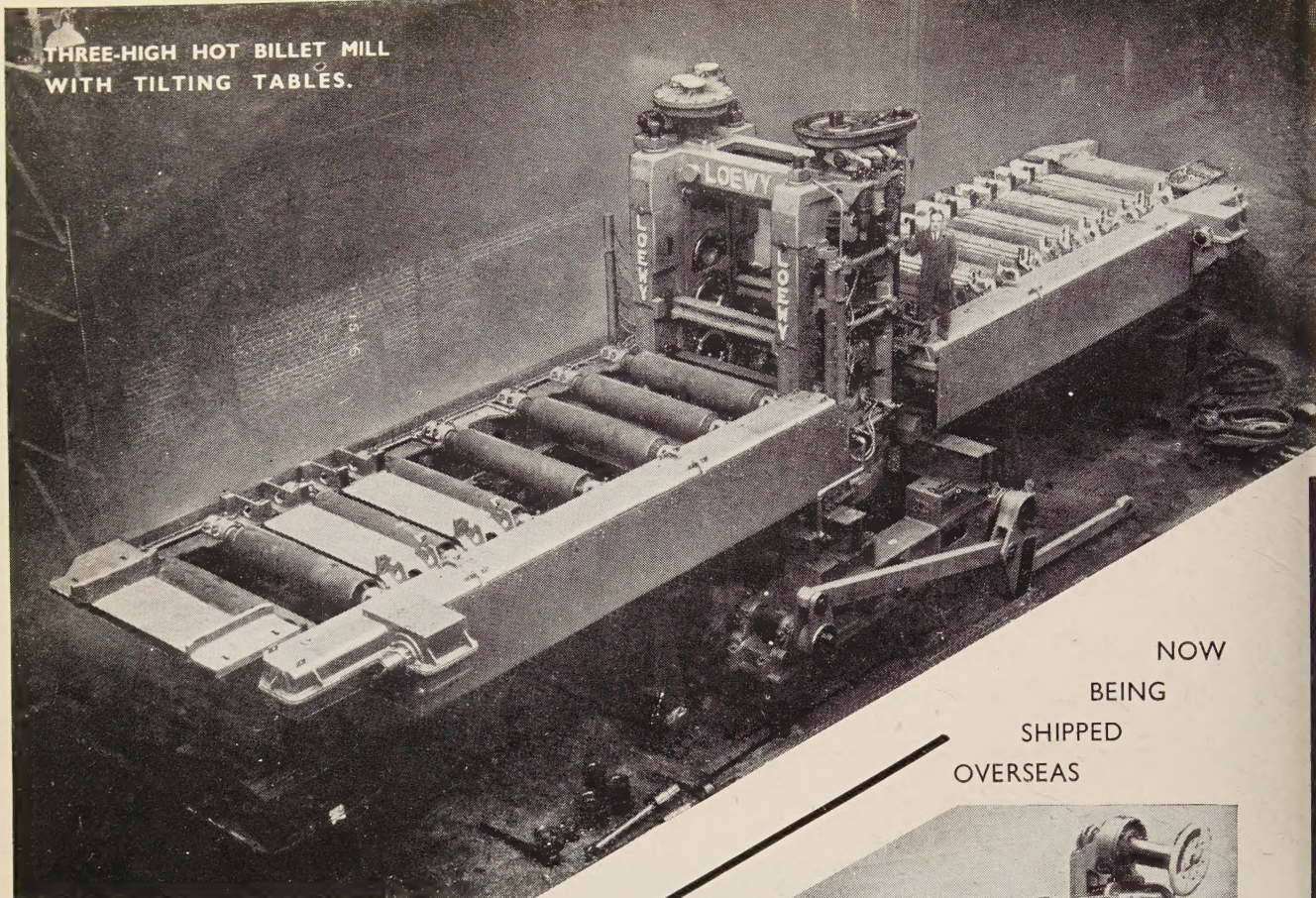
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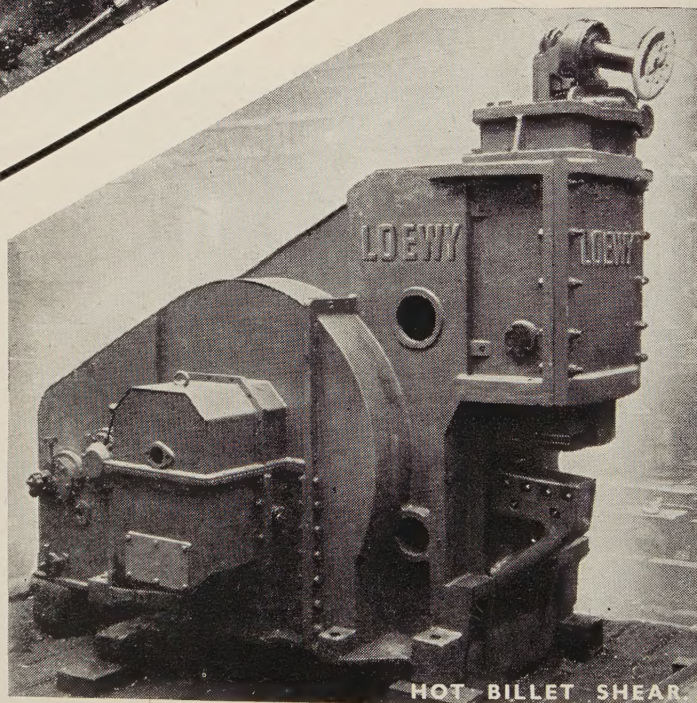
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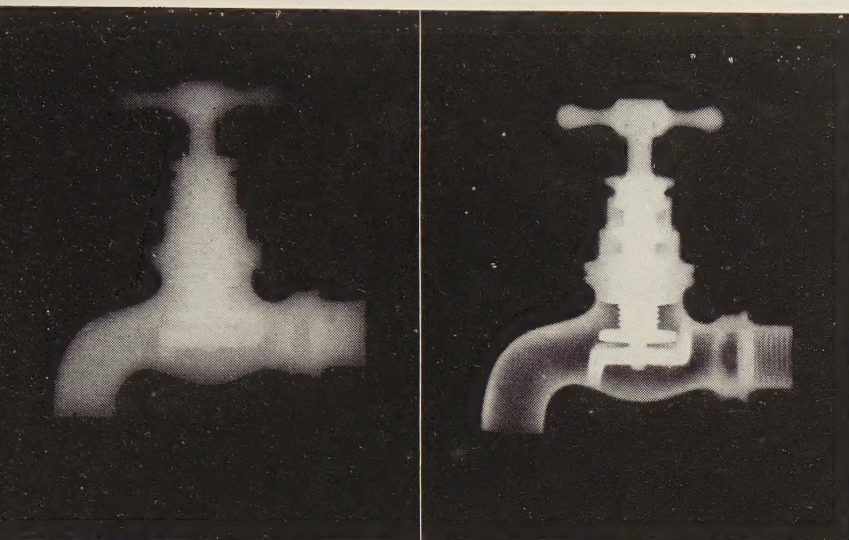
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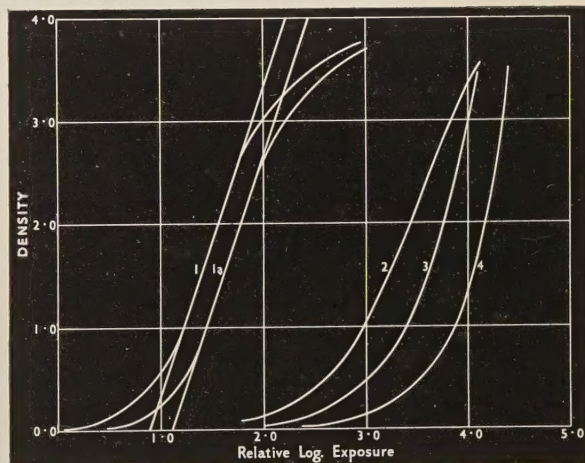
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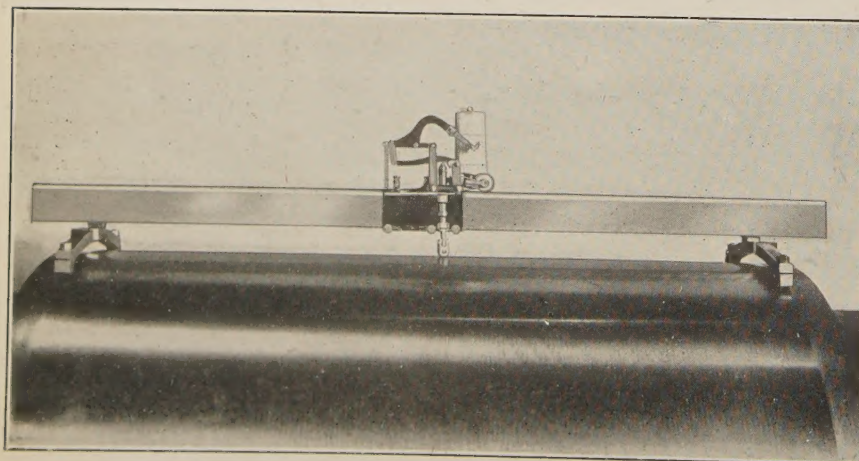
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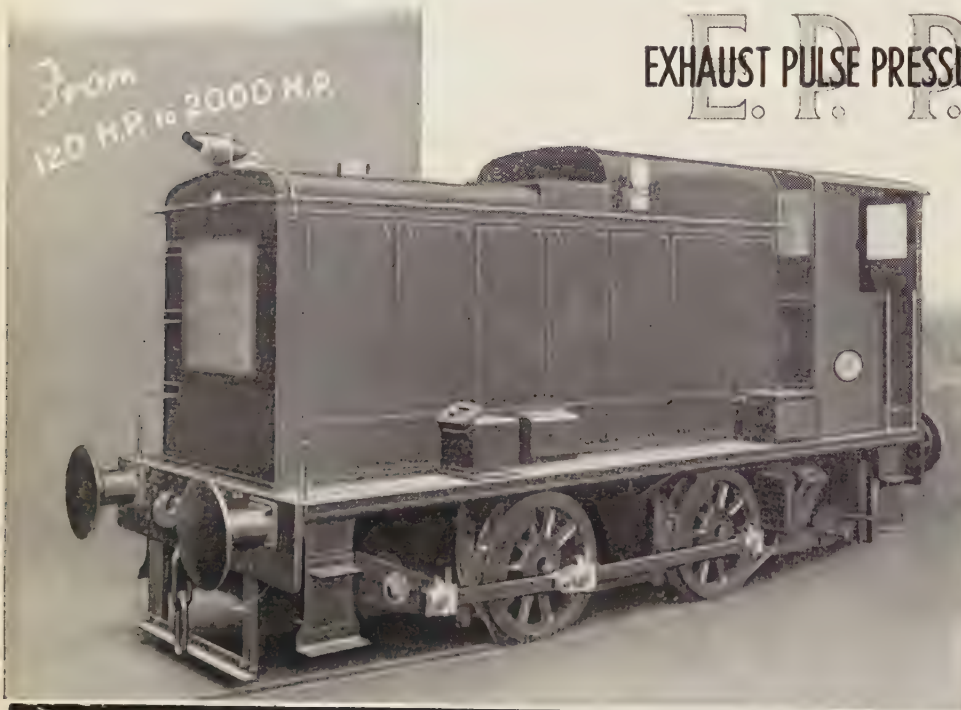
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By

G. V. RAYNOR, M.A., D.Phil.

Research Fellow in Theoretical Metallurgy, Birmingham University

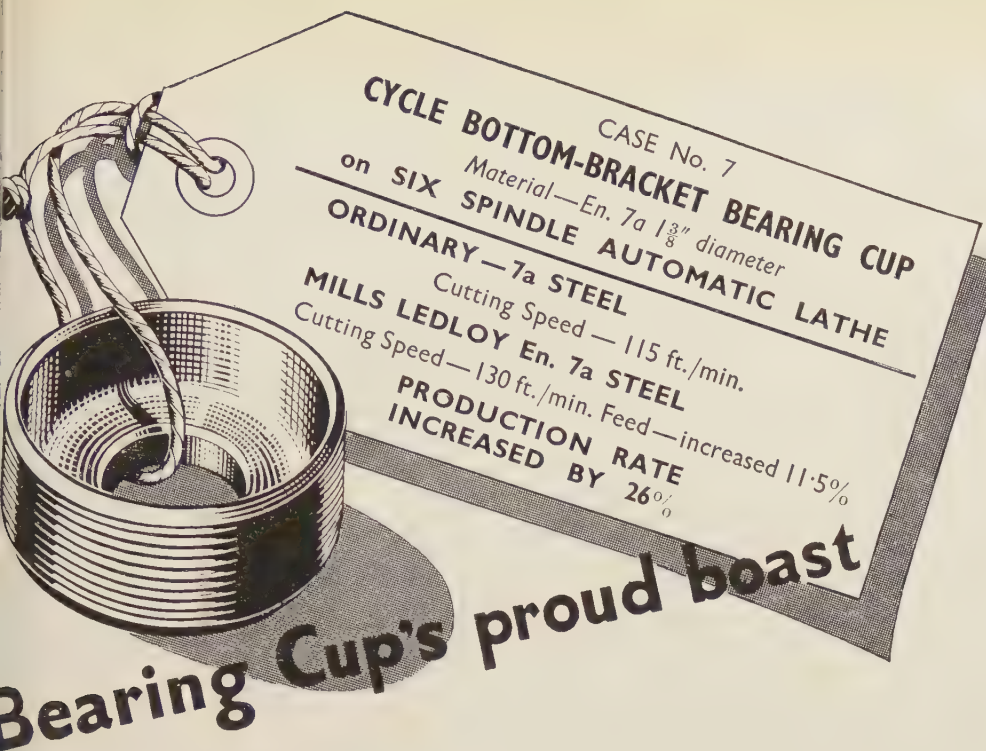
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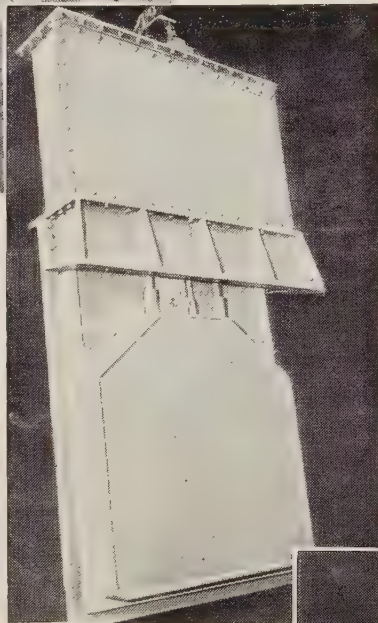
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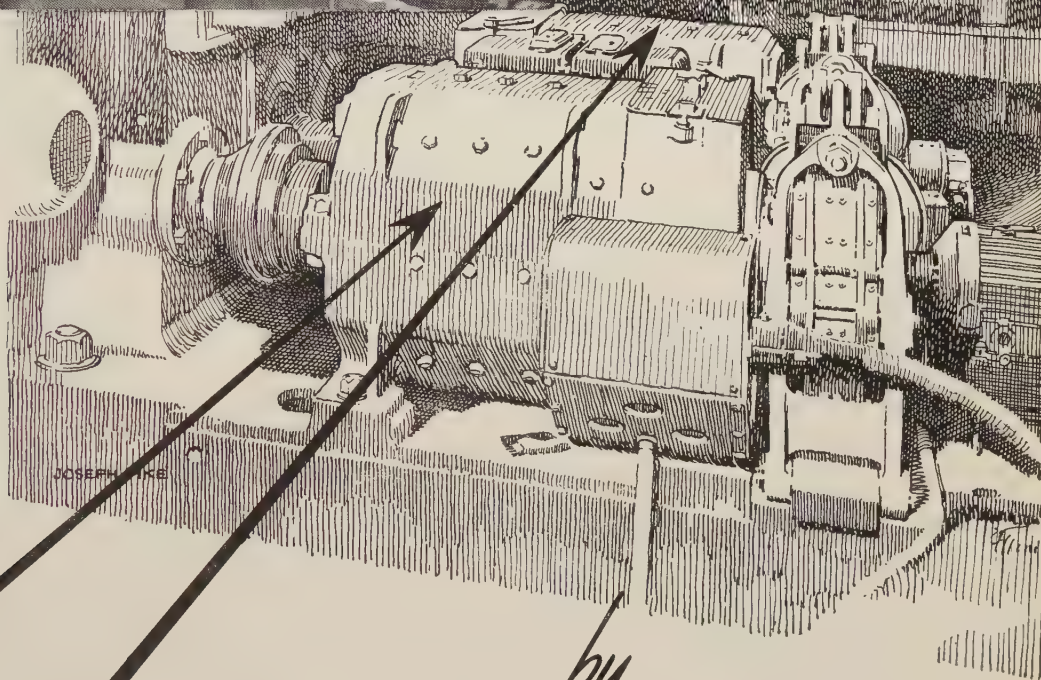
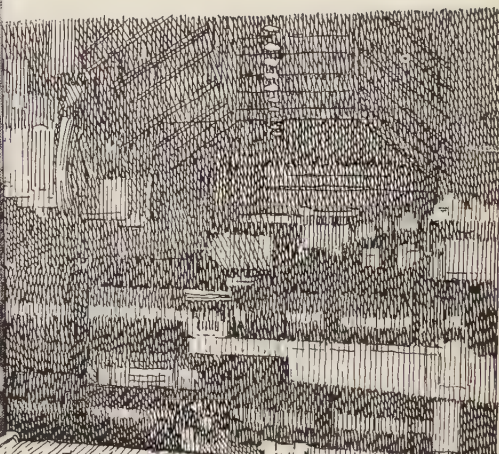
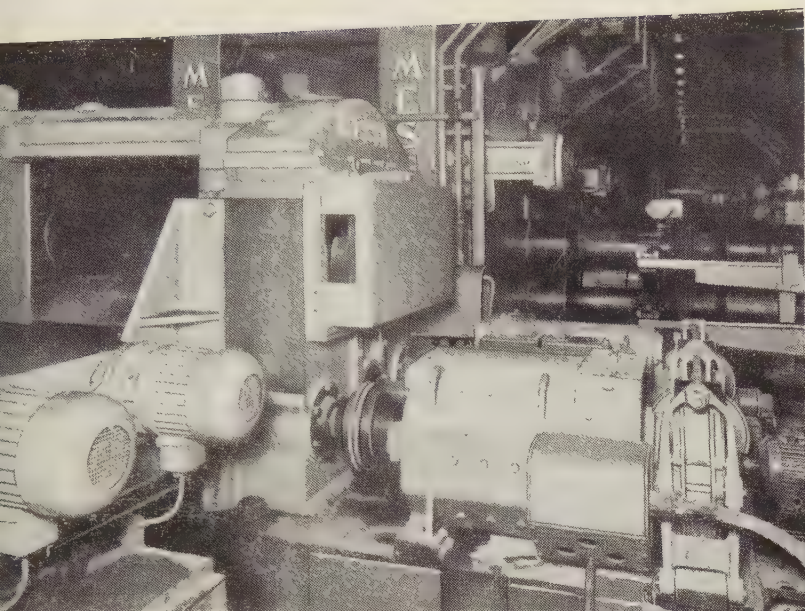


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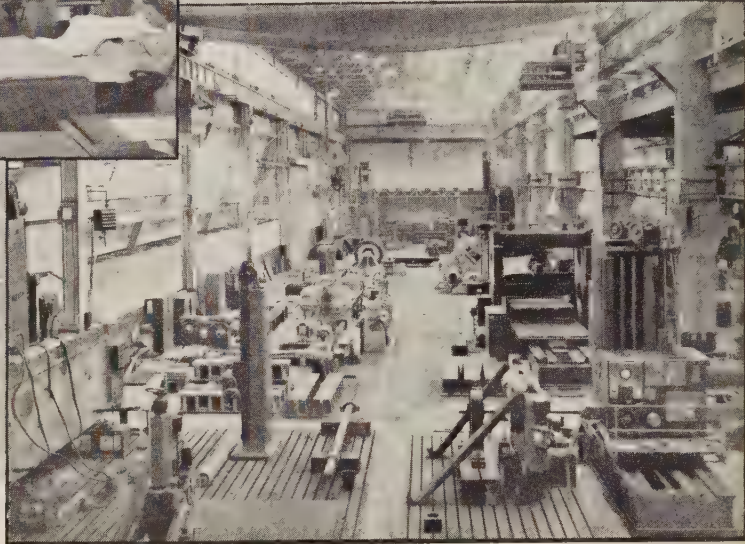
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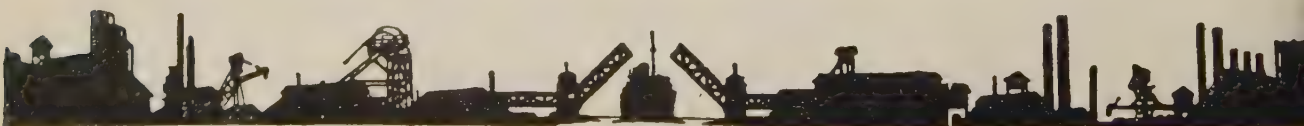
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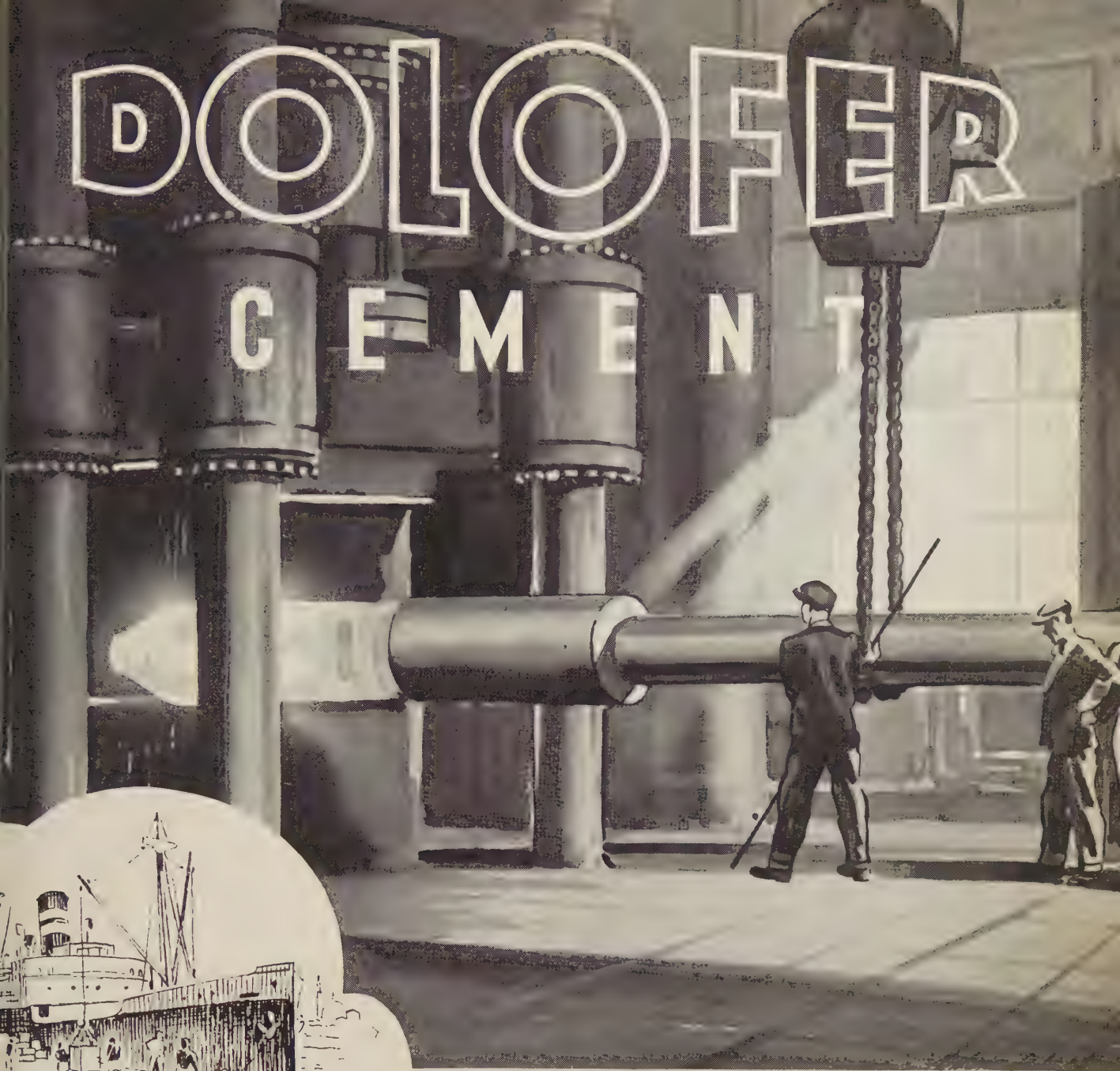
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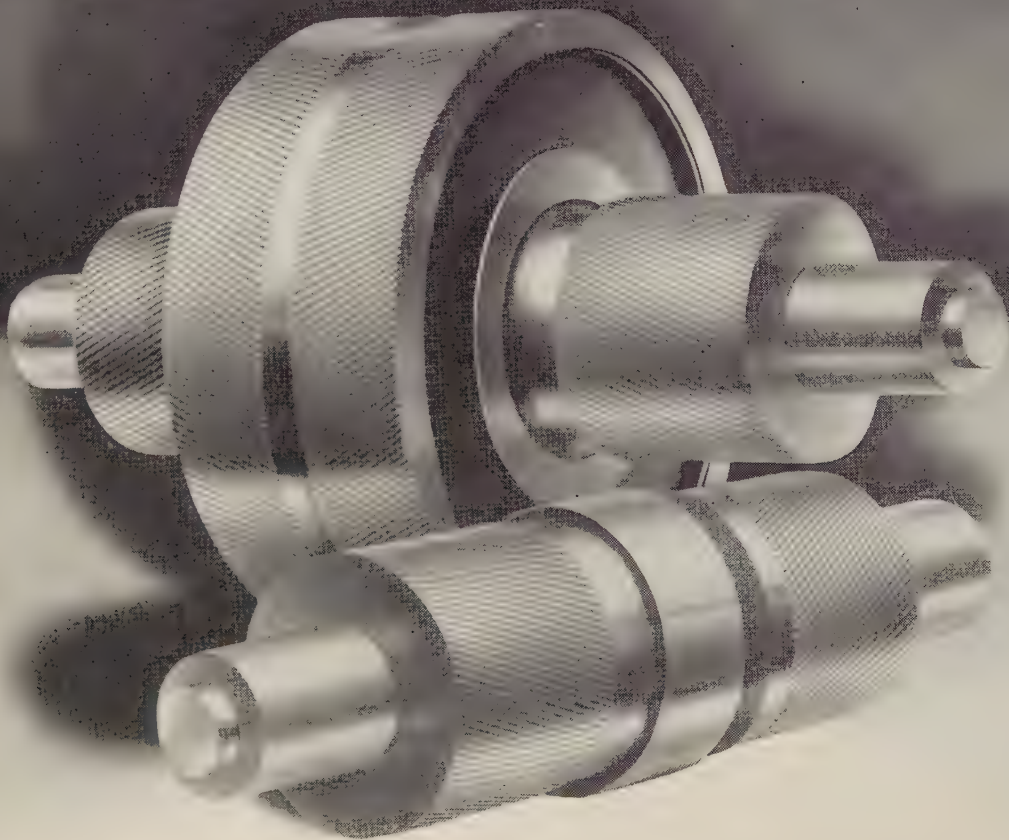
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MR. W. F. CARTWRIGHT

WILLIAM FREDERICK CARTWRIGHT was born on 13th November, 1906, and was educated at Dragon School, Oxford, and at Rugby. In 1925 he commenced his engineering training as Chief Mechanical Engineer's Pupil at the Great Western Railway Company's Swindon Works and, after three years, passed on to the Drawing Office in the early part of 1928.

In 1929 he joined Messrs. Guest, Keen and Nettlefolds, Limited, and took up an appointment at their Dowlais Works, where he remained until the autumn of 1930. In that year he was given the opportunity to broaden his experience by a first-hand study of practice in Continental iron and steel works, so the following twelve months were spent as a student at the works of Hoesch Köln, A.G., at Dortmund ; August Thyssen Hütte, Duisburg ; A.R.B.E.D. Esch, Luxemburg ; and de Wendel et Cie.

Towards the end of 1931 Mr. Cartwright returned to this country and became Assistant to the Works Manager of the Port Talbot Works of the Guest Keen Baldwins Iron and Steel Co., Ltd. After serving for four years in that capacity he was appointed Technical Assistant to the Managing Director, and held this position until 1940 ; it was during this period that the East Moors Works of Guest Keen Baldwins were reconstructed and enlarged, and he was very largely concerned with this important undertaking.

In 1940 he was elected to the Board of Directors of Guest Keen Baldwins Iron and Steel Co., Ltd., and at the same time was appointed the Company's Chief Engineer. Further promotion came three years later, when, in 1943, he became General Manager of the Company's Margam and Port Talbot Works : this is the position he holds to-day.

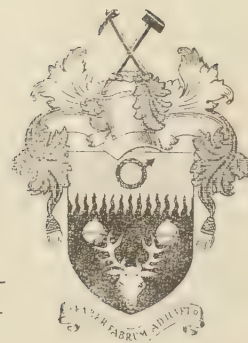
Mr. Cartwright was elected a Member of the Iron and Steel Institute in 1936. Last year, when the Council appointed an Engineering Committee to form an Iron and Steel Engineers Group, he became the first Chairman, and the success which has so far attended the Group's operations is largely due to his drive and enthusiasm. In view of his services to the Institute it was appropriate that Mr. Cartwright should have been elected a Member of Council in 1946.



W. F. Cartwright, Esq., A.M.I.Mech.E.
Chairman of the Iron and Steel Engineers Group, 1946-1947

PROCEEDINGS OF THE INSTITUTE

REPORTS OF COUNCIL · OFFICIAL NOTICES



REPORT OF COUNCIL FOR 1946

THE Council submit this, their Annual Report and Statement of Accounts for the year 1946, to Members for their approval at the Seventy-Eighth Annual General Meeting of the Iron and Steel Institute. In some sections information later than 31st December, 1946, has been included.

The year under review has been a period of transition from war-time activities to those of peace. Conditions are still far from settled. Nevertheless, progress has been substantial. Close collaboration with the British Iron and Steel Research Association has been established on a basis which the Council believe will prove mutually beneficial. The *Journal* is being issued monthly from 1st January, 1947, in a revised and enlarged form and more Special Reports have been published. The Library and Information Departments are being reorganized and the service they provide for Members, the Research Association, and the Industry is being extended. An Engineers Group has been formed and the first meetings give promise of permanent success. Contact has been re-established with overseas Members in

many countries and new connections have been started. Members of the staff who were serving in the Forces have returned and additional staff has been engaged.

ROLL OF THE INSTITUTE

Membership at the end of the year totalled 4044, an increase of 688, or 20% over the record figure of the previous year. Particulars are given in Tables I, II, and III, and in Fig. 1.

The growth in both the home and overseas membership is satisfactory. The number of Home Members (including Associates) increased by 15% and the number of Overseas Members by 42%. The latter numbered 886 (or 28% of the total) so that the loss resulting from the war has been more than made good. The number of Associates

TABLE II—*Joint Membership with the Institute of Metals at 31st December, 1946*

	Home Members		Overseas Members		Total	
	Ordinary	Joint ¹	Ordinary	Joint ¹	Ordinary	Joint ¹
Patron	1	....	....	....	1	....
Hon. Members . . .	7	3	7	1	14	4
Life Members . . .	39	8	17	3	56	11
Ord. Members . . .	1843 ²	697	611 ³	205	2454	902
Total (Members)	1890	708	635	209	2525	917
Associates	242	318	28	14	270	332
Total (classified)	2132	1026	663	223	2795	1249
Total Membership	..	..	..	..	4044	

TABLE I—*Membership at 31st December, 1946, and Preceding Six Years*

At 31st December :	1940	1941 ¹	1942	1943	1944	1945	1946
Patron	1	1	1	1	1	1	1
Hon. Members . . .	14	15	14	12	13	16	18
Life Members . . .	67	60	60	64	65	67	67
Ord. Members ² . .	2336	2213	2213	2354	2482	2736	3356
Associates	248	262	295	369	473	536	602
Total	2666	2551	2583	2800	3034	3356	4044

¹ Revised.

² The above figures include six Members for 1942, seven for 1943, nine for 1945 and 1946, and eight for the other years whose names were retained in the List of Members in an honorary capacity by order of the Council.

¹ Members who are also Members of the Institute of Metals.

² Includes eight Members whose names were retained in the List of Members in an honorary capacity by order of the Council.

³ Includes one Member whose name was retained in the List of Members in an honorary capacity by order of the Council.

TABLE III—*Home and Overseas Membership, 1939 to 1946*

At 31st December :	1939		1940		1941		1942		1943		1944		1945		1946	
	Class	Totals	Class	Totals	Class	Totals	Class	Totals	Class	Totals	Class	Totals	Class	Totals	Class	Totals
Patron	1		1		1		1		1		1		1		1	
Hon., &c., Members :		1		1		1		1		1		1		1		1
Home	3		4		5		5		5		6		10		10	
Overseas	12		10		10		9		7		7		6		8	
Life Members :		15		14		15		14		12		13		16		18
Home	40		40		40		39		43		44		47		47	
Overseas	28		27		20		21		21		21		20		20	
Ordinary Members :		68		67		60		60		64		65		67		67
Home	1622		1673		1698		1753		1883		2017		2180		2540	
Overseas	785		663		515		460		471		465		556		816	
Associates :		2407		2336		2213		2213		2354		2482		2736		3356
Home	171		208		227		261		332		438		494		560	
Overseas	42		40		35		34		37		35		42		42	
Totals :		213		248		262		295		369		473		536		602
Home	1837		1926		1971		2059		2264		2506		2732		3158	
Overseas	867		740		580		524		536		528		624		886	
Total Membership		2704		2666		2551		2583		2800		3034		3356		4044

was 602, an increase of 11% ; of these 55% were members also of the Institute of Metals. The total figures included 917 Members, 329 Student Members, and 3 Associates of the Institute of Metals (a total of 1249) and 365 Fellows, 306 Associates, and 133 Licentiates of the Institution of Metallurgists (a total of 804). The concessions made by the Councils of both Institutes to those who are under the age of 28, and the reciprocal arrangements for reduced subscriptions for joint membership made by the three societies, have therefore been amply justified.

The current Roll of Members does not include 33 Members and 21 Associates who have been placed on suspense lists.

Thirty-nine deaths were reported during the year and 75 Members and Associates resigned ; 35 were struck off the List of Members owing to non-payment of subscriptions and 6 were transferred to the military service suspense list. Six hundred and seventy-one Members and 172 Associates were newly elected or reinstated.

OBITUARY

The Council regret to record the deaths of the following 28 Members which occurred during the year 1946 :

AUSTIN, J. (Gowerton, Glam.)	29th March.
BAIKOFF, Professor A. A. (Moscow)	April.
BARBANSO, G. (Luxembourg)	4th May.
BLYDE, J. E. A. (Sheffield)	31st May.
BREARLEY, A. W. (Sheffield)	3rd November.
CARLISLE, C. G. (Sheffield)	18th January.
DAVIES, B. G. (Pontypool, Mon.)	29th April.
GLASS, J. R. (London)	13th November.
GREIG, E. C. (Sheffield)	13th May.
GUILLET, Professor L. (Paris)	9th May.
IZOD, E. G. (Addlestone, Surrey)	2nd October.

JACKS, H. B. (Barnt Green, Worcs.)	27th November.
JACKSON, G. M. (Chesterfield)	9th September.
MOORE, S. O. (Wolverhampton)	31st March.
MORGAN, J. V. (Irlam, near Manchester)	June.
MORRISON, T. (Pittsburgh, Pa., U.S.A.)	26th October.
PAUL-CAVALLIER, M. (Nancy, France)	February.
PEACOCK, T. S. (Kingswinford, Staffs.)	16th February.
PRETET, E. (Ugine, France)	1st March.
SAMUELSON, Sir FRANCIS. Bt. (Thirsk, Yorks.)	3rd January.
SOUTTER, J. W. P. (Manchester)	28th June.
TAYLOR, B. (Beeston, Notts.)	7th September.
VESSEY, J. W. (Lytham, Lancs.)	28th November.
WILLIAMS, S. VAUGHAN (Kenton, Middlesex)	7th August.
WILSON, R. (London)	21st February.
WRAIGHT, E. A. (Banstead, Surrey)	August.
WRIGHT, C. W. (Sheffield)	28th September.
WRIGHT, H. E. (Middlesbrough)	28th March.

The deaths of the following 11 Members took place earlier than 1946 but were not previously reported :

BOËL, Monsieur le Baron POL (Brussels)	1941.
BOYLE, Sir EDWARD (Cheshelbourne, Dorset)	31st March, 1945.
CLERF, FRANÇOIS (Denain, France)	26th June, 1941.
COQUEUGNOT, H. (Paris)	23rd January, 1944.
DAVIDGE, R. H. (Sketty, Swansea)	7th June, 1945.
GREEN, A. C. (Newport, Mon.)	1st April, 1945.
JOHNSON, H. A. (Stockholm)	10th July, 1941.
LEWIS, E. H. (Llanelly, Carmarthenshire)	21st July, 1945.
LISTER, W. (Corby, Northants.)	October, 1945.
MORGAN, G. V. (London)	31st May, 1945.
WARD, G. O. (Cleveland, Ohio, U.S.A.)	1945.

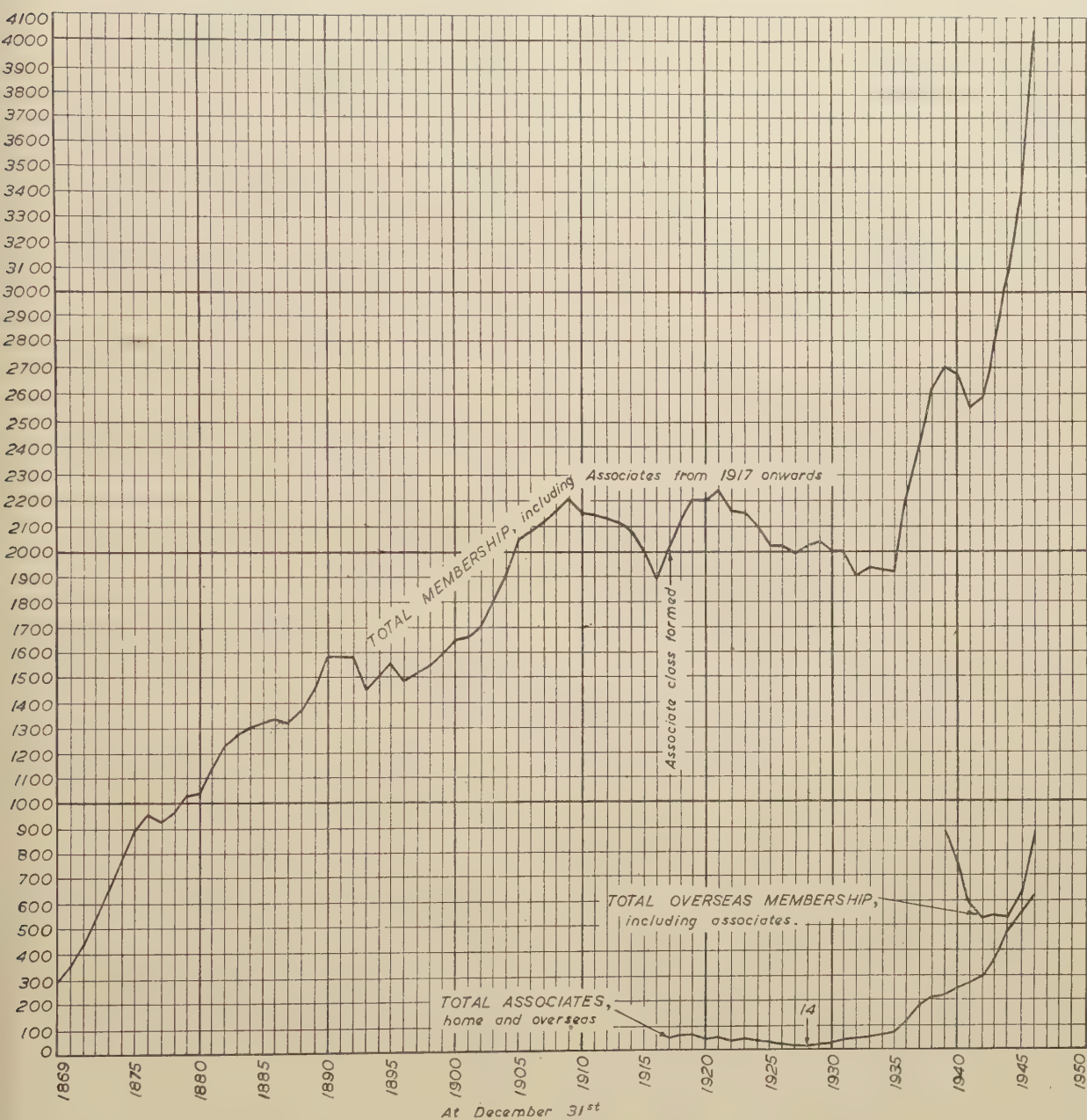


FIG. 1—Variation of the membership of the Institute since its formation in 1869

Sir Francis Samuelson was a Past-President of the Institute and had been a Member since 1885. Professor Guillet was an Honorary Vice-President. Mr. H. E. Wright received the Bessemer Gold Medal in 1945. Several of the deceased Members had been associated with the Institute for long periods, notably Baron Boël and Mr. Morrison (elected in 1895) and Mr. G. V. Morgan (1897).

The Council learned with much regret of the death on 12th January, 1947, of Dr. J. W. Donaldson, President of the West of Scotland Iron and Steel Institute and an Honorary Member of Council.

FINANCE

A report on finance is included at the end of this Report, and the accounts for the year ended 31st December, 1946, are appended.

CHANGES ON THE COUNCIL

(To 13th March, 1947)

At the Autumn General Meeting it was announced that the President, Dr. C. H. Desch, F.R.S., had, at the unanimous request of the Council, accepted nomination for another year.

During 1946 Mr. Fred Clements, Principal C. A. Edwards, F.R.S., Mr. E. J. Fox, Mr. J. S. Hollings, C.B.E., Sir William Larke, K.B.E., and Mr. C. E. Lloyd were nominated Honorary Vice-Presidents, and Mr. W. J. Dawson, Mr. G. H. Latham, and Mr. James Mitchell Vice-Presidents.

Mr. D. F. Campbell (Davy and United Engineering Co., Ltd.), Mr. W. F. Cartwright (Guest Keen Baldwins Iron and Steel Co., Ltd.), Dr. J. W. Jenkin (Tube Investments, Ltd.), Sir Arthur Matthews, O.B.E. (Thos. Firth and John Brown, Ltd.), and Mr. C. R. Wheeler, C.B.E. (Guest Keen Baldwins Iron and Steel Co., Ltd.), were elected Members of Council.

Sir John Duncanson (Commercial and Technical Director, The British Iron and Steel Federation) accepted an invitation to be an Honorary Member of Council; Dr. J. E. Hurst and Mr. W. W. Stevenson were nominated Honorary Members of Council by the Institution of Metallurgists.

The following also agreed to serve as Honorary Members of Council during their presidencies of the societies named, in succession to their predecessors: Colonel P. G. J. Gueterbock, C.B., D.S.O., M.A. (Institute of Metals, following Sir William Griffiths), Mr. Chris Moody (Cleveland Institution of Engineers, following Mr. J. H. Patchett), Wing Commander J. B. R. Brooke (Lincolnshire Iron and Steel Institute, following Mr. C. A. J. Behrendt), Mr. H. Bull (Sheffield Metallurgical Association,

following Mr. A. A. Munro), Mr. Ambrose Firth (Sheffield Society of Engineers and Metallurgists, following Mr. F. Wardrobe), Mr. G. B. Morrison (Staffordshire Iron and Steel Institute, following Dr. J. E. Hurst), and Mr. G. J. Jones (Swansea and District Metallurgical Society, following Captain H. Leighton Davies, C.B.E.).

Principal C. A. Edwards, F.R.S., and Mr. D. R. Lysaght resigned from the Council.

Since the beginning of 1947 Mr. W. B. Baxter and Mr. H. H. Burton have been nominated Vice-Presidents and Mr. D. A. Oliver (William Jessop and Sons, Ltd.), Mr. F. Saniter (The United Steel Companies, Ltd.), and Dr. C. Sykes, F.R.S. (Thos. Firth and John Brown, Ltd.) were elected Members of Council. Mr. T. F. Russell (English Steel Corporation, Ltd.) has succeeded Mr. H. Bull as President of the Sheffield Metallurgical Association and as an Honorary Member of Council.

In accordance with Bye-Law No. 10, the names of the Vice-Presidents and Members of Council due to retire at the Annual Meeting, 1947, were announced at the Autumn Meeting, 1946. Mr. Hollings having subsequently become an Honorary Vice-President and Mr. H. H. Burton a Vice-President, Mr. R. Mather and Sir Arthur Matthews respectively retire in their place.

The list is accordingly as follows:

Vice-Presidents—Captain H. Leighton Davies, C.B.E., Mr. G. H. Latham, and Mr. R. Mather.

Members of Council—Mr. R. A. Hacking, Mr. J. Sinclair Kerr, Mr. N. H. Rollason, Mr. D. F. Campbell, and Sir Arthur Matthews.

No other Members having been nominated up to one month before the Annual Meeting, the retiring Members are presented for re-election.

BESSEMER GOLD MEDAL

The Bessemer Gold Medal for 1946 was awarded to Mr. J. S. Hollings, C.B.E., in recognition of his distinguished services in encouraging technical improvement in the manufacture of iron and steel.

The Bessemer Gold Medal for 1947 has been awarded to Sir William Larke, K.B.E., in recognition of his distinguished services in promoting research in the iron and steel industries.

ANDREW CARNEGIE MEDALS

An Andrew Carnegie Silver Medal for 1945 has been awarded to Dr. M. Balicki for his report on "A Study of Work-Hardening and Re-annealing of Iron" (Volume No. I of the *Journal* for 1945).

An Andrew Carnegie Gold Medal for 1946 has been awarded to Mr. H. Morrogh for his report

on "The Neutralization of Sulphur in Cast Iron by Various Alloying Elements" (Volume No. II for 1946).

ANDREW CARNEGIE RESEARCH SCHOLARSHIPS

No grant was made by the Council during 1946.

WILLIAMS PRIZE

The Williams Prize for 1946 was awarded jointly to Dr. B. Jones and Mr. I. Jenkins for their paper on "New Annealing Plant for Steel Strip in Coils at the Whitehead Iron and Steel Co., Ltd., Newport, Mon." The paper will be found in the No. II volume of the *Journal* for the year.

TRUST FUNDS

Mr. N. H. Rollason was appointed a Trustee of the Andrew Carnegie Research Fund and of the Williams Prize Fund. The Trustees of the Trust Funds are now as follows :

Andrew Carnegie Research Fund—Sir William Larke, K.B.E., The Hon. R. G. Lyttelton, Mr. N. H. Rollason.

Williams Prize Fund—Sir William Larke, K.B.E., The Hon. R. G. Lyttelton, Mr. N. H. Rollason.

Bessemer Medal Fund—Mr. Desmond Lysaght, The Hon. R. G. Lyttelton, Mr. N. H. Rollason.

THE WORSHIPFUL COMPANY OF BLACKSMITHS

No recommendation for admission to the Worshipful Company of Blacksmiths was made during the year.

MOND NICKEL FELLOWSHIPS IN METALLURGY

As announced at the Annual General Meeting in 1946, the Council gratefully accepted a generous offer, made in a letter dated 27th February, 1946, by Sir William Griffiths, D.Sc., Chairman and Managing Director, on behalf of The Mond Nickel Company, Ltd., to present jointly to the Institute, the Institution of Mining and Metallurgy, the Institute of British Foundrymen, the Institute of Metals, and the Institution of Metallurgists such annual sums of money during the next seven years as will provide a total of £50,000 for the purpose

of establishing Fellowships in Metallurgy. Means of giving effect to the donor's intention are under consideration and an announcement will be made when the arrangements have been completed. The Fellowships will be known as the "Mond Nickel Fellowships in Metallurgy."

MEETINGS

Annual General Meeting

Technical Sessions—The Annual Meeting was held at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W.1, on Wednesday and Thursday, 1st and 2nd May, 1946, with sessions at 9.45 A.M. and 2.30 P.M. on the first day and at 9.0 A.M. on the second. Mr. Arthur Dorman (Retiring President) presided for part of the first session on the Wednesday and Dr. C. H. Desch, F.R.S., after his induction as President, for the rest of the sessions on Wednesday and on Thursday. Nine papers were discussed. (For the *First Hatfield Memorial Lecture* see below).

Luncheon—A luncheon for Members at the Connaught Rooms, London, on 2nd May was well attended, over 500 Members and guests being present.

Autumn General Meeting

Technical Sessions—The Autumn Meeting was held at the Institution of Civil Engineers, Great George Street, London, S.W.1, on Wednesday and Thursday, 13th and 14th November, 1946, with Dr. C. H. Desch, F.R.S. (President) in the Chair. The sessions commenced at 10.0 A.M. and 2.30 P.M. on the first day and at 9.30 A.M. on the second. Special Report No. 37 and nine papers were discussed.

Film Display—A display of technical films was given at 8.0 P.M. on the first day in the Lecture Theatre of the Institution of Civil Engineers.

HATFIELD MEMORIAL LECTURE

The First Hatfield Memorial Lecture was delivered by Dr. George B. Waterhouse, Professor Emeritus of the Massachusetts Institute of Technology, on the first day of the Annual General Meeting on 1st May, 1946, at 8.30 P.M. at the Institution of Civil Engineers, Great George Street, London, S.W.1. The Lecture, which was well attended by Members and guests, was entitled "The Services to Metallurgy of the late Dr. W. H. Hatfield, F.R.S." It is printed in the No. I Volume of the *Journal* for 1946.

IRON AND STEEL ENGINEERS GROUP

The President announced at the Annual General Meeting that the Council had decided to form an Iron and Steel Engineers Group within the framework of the Institute to hold meetings and discussions on subjects connected with iron and steel works engineering. The Engineering Committee, appointed to organize the Group's activities, is composed as follows :

Chairman

Mr. W. F. CARTWRIGHT

Members

Mr. W. B. BAXTER
Mr. W. R. BROWN, D.S.O.
Mr. H. S. CARNEGIE
Mr. M. A. FIENNES
Mr. E. T. JUDGE
Mr. H. H. MARDON
Mr. I. S. SCOTT-MAXWELL

Ex Officio

Dr. C. H. DESCH, F.R.S. (President)
The Hon. R. G. LYTELTON (Honorary Treasurer)

Membership of the Group is open, without additional fee, to all Members and Associates of the Institute. The membership of the Group as at 31st December, 1946, numbered 994.

The Group will co-operate closely with the affiliated Local Societies and with British and foreign engineering institutions. It will hold meetings in London and in the provinces.

Two full-day meetings were organized in 1946 ; both meetings were held at 4, Grosvenor Gardens, London, S.W.1, with Mr. W. F. Cartwright in the Chair. The following subjects were discussed :

First Meeting, Wednesday, 16th October, 1946—

"Steelworks Locomotives—Diesel *versus* Steam."
"A.C. and D.C. Drive for Steelworks Cranes and Ore Bridges."

Second Meeting, Wednesday, 11th December, 1946—

"Lubrication in Iron and Steelworks Engineering."
"Roll-Neck Bearings."

The Group will hold three meetings in London in 1947, in addition to others in the provinces. Those in London will be held at the offices of the Institute, as follows :

Wednesday, 26th February, 1947—

"The Blast-Furnace of To-day."

Wednesday, 11th June, 1947—

"Steam Generation and Utilization in Iron and Steel Works."
"The Application of Gas Turbines to Iron and Steel Works Practice."

Wednesday, 26th November, 1947—

"Rolling-Mill Drives and their Auxiliaries."

Full accounts of all meetings will be published in the *Journal*.

PUBLICATIONS

The Journal—In accordance with the intention announced in the last Report, the *Journal* was printed during the year with a quarto size of page and since January, 1947, has been issued monthly. The contents of the monthly *Journal*, except the advertisements, will be bound into three volumes each year. One copy of each monthly *Journal*, will be issued free of charge to each member. Appropriate volume binding cases (January to April, May to August, and September to December) and indexes will be issued only on request. Additional copies and bound volumes can be purchased, the prices being :

	Published Price	Members Rate
Annual set of the monthly <i>Journal</i> , or three bound volumes	£5 0 0	£3 3 0
Single copy, monthly <i>Journal</i>	10 0	7 6

During 1946 advance copies of papers were issued each month as usual and are being reprinted to form the usual two volumes, Nos. CLIII and CLIV. The first volume contains thirteen papers, including eight published under the auspices of the Joint Research Committees of the Institute and the British Iron and Steel Research Association ; the second volume contains twenty-one papers, of which eight are Joint Research Committee papers and one an Andrew Carnegie Research Report.

The Bulletin of the Iron and Steel Institute was published monthly as heretofore but ceased to appear as a separate publication at the end of the year, being now incorporated in the monthly *Journal*.

Special Reports—The following seven Special Reports were issued in respect of 1946, publication being in some cases deferred to the Spring of the following year :

Special Report No. 31. "The Effect of Different Methods of Pretreating Iron and Steel before Painting." By F. FANCUTT. [Paper No. 17/1946 of the Corrosion Committee (submitted by the Protective Coatings Sub-Committee)].

Special Report No. 32. "Third Report on Refractory Materials." A Report by the Joint Refractories Research Committee of the British Iron and Steel Research Association and the British Refractories Research Association.

Special Report No. 33. "The Development of Monolithic Dolomite Linings." By the Technical Panel of the Basic Furnace Linings Committee.

Special Report No. 34. "First Report of the Rolling-Mill Research Sub-Committee of the Iron and Steel Industrial Research Council."

Special Report No. 35. "Second Report on the Development of Monolithic Dolomite Linings." By the Technical Panel of the Basic Furnace Linings Committee.

Special Report No. 36. "Symposium on the Hardenability of Steel." Organized by the Technical Advisory Committee of the Special and Alloy Steels Committee (Ministry of Supply) and the Iron and Steel Institute.

Special Report No. 37. "The Influence of Port Design on Open-Hearth Furnace Flames." By J. H. CHESTERS and M. W. THRING.

Translation Service—Translations of thirty-seven foreign technical papers (Nos. 258 to 294) were included in the Institute's Translation Series; they are obtainable by Members at 10s. each (5s. for each additional copy of the same translation). The Council wish to record their appreciation of the collaboration received from a number of Companies, Research Associations, and Government Departments in making translations available for inclusion in the Translation Series. Some half-dozen translations which were not suitable for inclusion in the Series were also made for Members at their own cost.

JOINT LIBRARY AND INFORMATION DEPARTMENT

Joint Library

The Council are pleased to note that increased use has been made of the Library facilities by Members and industrial companies. The number of loans made during the year reached the record high figure of 7,514 as compared with 6,752 in 1945.

Special efforts were made to obtain war-time German textbooks and a considerable number of these has been added to the Library. Other important textbooks have also been obtained either by purchase or by presentation and the Council wish to take this opportunity of thanking those who were good enough to present publications. Particulars of the literature added to the Library have been included in the list of additions published quarterly. This will be sent to Members on request.

Information Department

During the year plans were completed for the reorganization of the Information Department and an Information Officer was appointed.

The Universal Decimal Classification System has been adopted as a basis for an index of technical information. This should result in a minimum of delay in answering Members' enquiries and supplying bibliographies.

Members seeking information on the technical literature are invited to avail themselves of the service provided.

JOINT COMMITTEE ON METALLURGICAL EDUCATION

The Joint Committee on Metallurgical Education has issued a brochure on "Metallurgy—A Scientific Career in Industry," which has secured a wide circulation among schools, technical colleges, and industrial companies.

In addition to nominees of the Iron and Steel Institute, the Institution of Mining and Metallurgy, the Institute of British Foundrymen, the Institute of Metals, and the Institution of Metallurgists, the Committee now includes representatives of teachers of metallurgy at universities and technical colleges.

The services of the Institute's Education Officer have been placed at the disposal of the Committee.

NATIONAL CERTIFICATES IN METALLURGY

During the academic year 1945–46 a successful beginning was made with the scheme for National Certificates in Metallurgy. Courses were approved at ten colleges and the first examinations held at four of these. More courses have been approved to date for the current academic year, and a considerable number of applications for approval are awaiting consideration by the Joint Committee; this is composed of representatives of the Ministry of Education, the Institution of Mining and Metallurgy, and the Institute of Metals, in addition to nominees of the Institute.

RELATIONS WITH OTHER SOCIETIES AND TECHNICAL INSTITUTIONS

The Institute's friendly relations with scientific societies and technical institutions in Great Britain and countries overseas were maintained. Arrangements have been made whereby Members, or the staffs of companies which are Members, of the undermentioned societies overseas are admitted to membership of the Institute at an annual subscription of £2 12s. 6d. instead of £3 3s. 0d. (Associates up to the age of 28: £1 1s. 0d. instead of £1 5s. 0d.):

American Institute of Mining and Metallurgical Engineers. (*The Associate age limit is 33.*)

American Iron and Steel Institute
 American Society for Metals
 Association Luxembourgeoise des Ingénieurs et Industriels (Luxembourg)
 Canadian Institute of Mining and Metallurgy
 Jernkontoret (Sweden)
 Koninklyk Instituut van Ingénieurs (Holland)
 Norsk Metallurgisk Selskap (Norway)
 Société Française de Métallurgie (France)
 Société Royale Belge des Ingénieurs et des Industriels (Belgium)

Co-operation with the Institute of Metals

The long-standing friendly collaboration between this Institute and the Institute of Metals continued during the year on the same basis as before. There was a Joint Secretary and some of the staff served both Institutes. Reference has already been made to the extent of the Joint Membership.

Affiliation with Local Societies

As announced last year the following local societies are now affiliated to the Institute :

Cleveland Institution of Engineers
 Leeds Metallurgical Society
 Lincolnshire Iron and Steel Institute
 Newport and District Metallurgical Society
 Sheffield Society of Engineers and Metallurgists
 Staffordshire Iron and Steel Institute
 Swansea and District Metallurgical Society

The societies retain their complete independence but have agreed to invite Institute Members to attend meetings organized by them in their districts.

Co-operation with other Local Societies

The Council are glad to record once again the continued friendly relations existing with the following societies on the same basis as in previous years :

Ebbw Vale Metallurgical Society
 Manchester Metallurgical Society
 Sheffield Metallurgical Association
 West of Scotland Iron and Steel Institute

Meetings with other Societies

For the period from 1st April, 1946, to 30th April, 1947

Members of the Institute were invited to take part in numerous meetings organized by the affiliated local societies. Special invitations to attend the following 12 meetings were issued (up to 30th April, 1947) :

Saturday, 27th April, 1946 : Newport and District Metallurgical Society

Place and Time : Newport Technical College at 6.30 P.M.

Chairman : Mr. C. H. Latham, J.P., President of the Society, and a Vice-President of the Institute.

Lecture : "The Future of Research in Industry," by Sir Charles Goodeve, O.B.E., D.Sc., F.R.S., Director of Research, the British Iron and Steel Research Association.

Monday, 21st October, 1946 : The Sheffield Society of Engineers and Metallurgists

Place and Time : The Royal Victoria Hotel, Sheffield, at 6.15 P.M.

Chairman : Mr. Ambrose Firth, President of the Society, and an Honorary Member of Council of the Institute.

Lecture : "The Layout and Mechanization of Continuation Merchant Mills," by Mr. W. Udall.

Saturday, 16th November, 1946 : Swansea and District Metallurgical Society

Place and Time : The Royal Institution, Swansea, at 6.30 P.M.

Chairman : Mr. G. J. Jones, President of the Society, and an Honorary Member of Council of the Institute.

Lecture : "Problems in Fuel Efficiency," by Dr. R. J. Sarjant, O.B.E.

Monday, 18th November, 1946 : Sheffield Society of Engineers and Metallurgists

Place and Time : Royal Victoria Hotel, at 6.15 P.M.

Chairman : Mr. Ambrose Firth, President of the Society, and an Honorary Member of Council of the Institute.

Lecture : "A Consideration of Liquid Fuel Firing, with Particular Reference to Open-Hearth Furnaces," by Mr. F. A. Gray.

Tuesday, 19th November, 1946 : The Lincolnshire Iron and Steel Institute

Place and Time : The Technical School, Cole Street, Scunthorpe, at 7.30 P.M.

Chairman : Mr. J. B. R. Brooke, President of the Lincolnshire Iron and Steel Institute, and an Honorary Member of Council of the Iron and Steel Institute.

Lecture : "The Influence of Limestone in the Blast-Furnace Stack," by Dr. H. L. Saunders.

Saturday, 14th December, 1946 : Swansea and District Metallurgical Society

Place and Time : The Royal Institution, Swansea, at 6.30 P.M.

Chairman : Mr. G. J. Jones, President of the Society, and an Honorary Member of Council of the Institute.

Lecture : "Recent Progress in Steel Plant Refractories and Furnace Design," by Dr. J. H. Chesters.

Monday, 16th December, 1946 : Sheffield Society of Engineers and Metallurgists

Place and Time : The Royal Victoria Hotel, Sheffield, at 6.15 P.M.

Chairman : Mr. Ambrose Firth, President of the Society, and an Honorary Member of Council of the Institute.

Lecture : "Some Recent Problems for Railway Metallurgists," by Dr. H. O'Neill.

Monday, 17th February, 1947 : Cleveland Institution of Engineers

Place and Time : Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough, at 6.30 P.M.

Chairman : Mr. Chris Moody, President of the Institution, and an Honorary Member of Council of the Institute.

Lecture : "The Influence of Limestone in the Blast-Furnace Stack," by Dr. H. L. Saunders.

Monday, 17th February, 1947 : Sheffield Society of Engineers and Metallurgists

Place and Time : The Royal Victoria Hotel, Sheffield, at 6.15 P.M.

Chairman : Mr. Ambrose Firth, President of the Society, and an Honorary Member of Council of the Institute.

Lecture : "Metallurgical Aspects of Compressed Gas Cylinders," by Dr. N. P. Allen.

Saturday, 22nd February, 1947 : Swansea and District Metallurgical Society

Place and Time : The Royal Institution, Swansea, at 6.30 P.M.

Chairman : Mr. G. J. Jones, President of the Society, and an Honorary Member of Council of the Institute.

Lecture : "Electro-tinning of Steel Strip in the Manufacture of Tinplate," by C. Frankel.

Saturday, 22nd March, 1947 : Swansea and District Metallurgical Society

Place and Time : The Royal Institution, Swansea, at 6.30 P.M.

Chairman : Mr. G. J. Jones, President of the Society, and an Honorary Member of Council of the Institute.

Lecture : "Rolling—with Special Reference to Strip," by Mr. S. E. Graeff.

Saturday, 26th April, 1947 : Swansea and District Metallurgical Society.

(Postponed from 18th January, 1947)

Place and Time : The Royal Institution, Swansea, at 6.30 P.M.

Chairman : Mr. G. J. Jones, President of the Society, and an Honorary Member of Council of the Institute.

Lecture : "The Manufacture of Rimming Steel for Deep Drawing," by Mr. S. R. Isaac.

Invitations were also received for Members to attend the following meetings ; those organized by the Sheffield Branch of the Institute of British Foundrymen and by the Ebbw Vale Metallurgical Society were joint meetings :

Tuesday, 15th October, 1946 : Sheffield Metallurgical Association

Place and Time : Sheffield Metallurgical Association, 198, West Street, Sheffield, 1, at 6.30 P.M.

Chairman : Mr. H. Bull, President of the Association, and an Honorary Member of Council of the Institute.

Lecture : "The Overheating of Steel," by Mr. A. Preece.

Monday, 11th November, 1946 : Sheffield Branch of the Institute of British Foundrymen

Place and Time : Royal Victoria Hotel, Sheffield, at 7.30 P.M.

Chairman : Mr. F. E. Steel, President of the Sheffield Branch of the Institute of British Foundrymen.

Lecture : "X-Ray Technique in the Examination of Steel Castings," by Dr. R. Jackson.

Wednesday, 4th December, 1946 : Manchester Metallurgical Society

Place and Time : Engineer's Club, Albert Square, at 6.30 P.M.

Chairman : Mr. R. S. Brown, President of the Society.

Lecture : "Function of Ductility in Engineering Design," by Dr. R. W. Bailey.

Tuesday, 11th March, 1947 : Ebbw Vale Metallurgical Society

Place and Time : The Rational Hall, Ebbw Vale, Mon, at 6.45 P.M.

Chairman : Mr. F. Llewellyn, Chairman of the Society.

Lecture : "The German Iron and Steel Industry—Impressions Gained from Recent Visits," by Mr. R. A. Hacking.

INSTITUTION OF METALLURGISTS

Mr. H. H. Burton and Mr. J. Sinclair Kerr were appointed representatives of the Institute on the Council of the Institution of Metallurgists. The Secretary continued to serve as Secretary of the Institution, the secretarial work of which was carried out by the staff of the Institute under an agreement.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Collaboration between the Institute and the British Iron and Steel Research Association was consolidated on a basis which the Council are confident will prove mutually advantageous over a period of years.

It has been agreed that the papers and reports emanating from the Research Committees or staff of the Research Association shall normally be published in the *Journal* or Special Report Series of the Institute. The Institute's Library and Information Department will provide service for the Research Association as well as for Members, and the Research Association will avail itself of the foreign connections which the Institute has established through its international membership and long-standing tradition. These services will be provided by the Institute at cost.

On the other hand, the Institute will cease organizing Research Committees and the responsibility for the Joint Research Committees, formerly organized by the Institute, has accordingly been transferred to the Research Association. The Steel Castings Research Committee was transferred as at 31st December, 1945, the Ingots Committee (formerly Heterogeneity of Steel Ingots Committee) at 30th April, 1946, the Alloy Steels Research Committee at 31st July, 1946, and the Corrosion Committee at 31st December, 1946. The last three Committees, together with their Sub-Committees, were reorganized during the year.

In the following list the number of meetings of the Joint Research Committees and Sub-Committees held in 1946, up to their dates of transfer to the Research Association, are indicated:

Alloy Steels Research Committee: Chairman, Mr. W. J. Dawson. Established June, 1934. Meetings held: three. Transferred 31st July, 1946.

Thermal Treatment Sub-Committee: Chairman, Mr. P. B. Henshaw. Established January, 1936. Meetings held: one.

Hair-Line Crack Sub-Committee: Chairman, Mr. H. H. Burton. Established July, 1938. Meetings held: three.

Special Aero-Components Sub-Committee: Established July, 1940. Meetings held: none recorded.

Corrosion Committee: Chairman, Mr. W. J. Dawson, later Professor G. Wesley Austin, O.B.E. Established July, 1928. Meetings held: four. Transferred 31st December, 1946.

Atmospheric Corrosion Sub-Committee: Chairman, Mr. T. Henry Turner. Established June, 1944. Meetings held: three.

Protective Coatings Sub-Committee: Chairman, Mr. T. M. Herbert. Established January, 1936. Meetings held: four.

Marine Corrosion Sub-Committee: Chairman, Professor J. E. Harris. Re-formed November, 1938. Meetings held: three.

Sub-Committee on the Corrosion of Buried Metals (working in collaboration with the Committee on Soil Corrosion of Metals and Cement Products of the Institution of Civil Engineers). Established October, 1937. No meetings held; activities carried on by correspondence.

Industrial Waters (Corrosion) Sub-Committee: Chairman, Dr. J. W. Jenkin. Established May, 1945. Meetings held: three.

Methods of Testing (Corrosion) Sub-Committee (previously sub-committee IS/28/1, Drafting Committee for Protective Coatings of Iron and Steel, of the British Standards Institution): Chairman, Dr. J. C. Hudson. Established November, 1945. Meetings held: seven.

Ingots Committee: Chairman, Mr. H. H. Burton. Established May, 1924. Meetings held: two. Transferred 30th April, 1946.

Ingot Moulds Sub-Committee: Chairman, Mr. R. H. Myers. Established November, 1934. Meetings held: one (special). (Stresses in Moulds Panel, none.)

Liquid Steel Temperature Sub-Committee: Chairman, Mr. E. W. Elcock. Established March, 1929. Combined with the Foundry Steel Temperature Sub-Committee of the Steel Castings Research Committee and transferred on 31st December, 1945.

Sub-Committee on Gaseous and Non-Metallic Inclusions (including the Oxygen Sub-Committee): Chairman, Mr. W. W. Stevenson. Established January, 1936: title changed February, 1944. Meetings held: one (Chemists Panel, two).

Inclusions Sub-Committee: Chairman, Mr. W. J. Dawson. Established November, 1936. Meetings held: three.

Standard Methods of Analysis Sub-Committee: Chairman, Dr. E. Gregory. Established September, 1939. Meetings held: one.

PRESENTATIONS AND LOANS

The Council record their thanks to Sir Hugh Bell, Bt., for the loan, in February, 1947, of portraits of his great-grandfather and grandfather, Sir Lowthian Bell and Sir Hugh Bell, first and second Baronets and former Presidents and Bessemer Gold Medallists.

STAFF

Miss J. Best, Major H. Davison, Mr. R. F. Flint, Mr. H. G. Hale, and Mr. J. C. Robinson resumed their duties with the Institute on demobilization from the armed forces; Major Davison resigned as from 31st August, 1946.

Mr. A. E. Chattin, who had been serving as Assistant Secretary to both the Institute of Metals and to the Iron and Steel Institute, gave up the former position at 30th June, 1946, when Lieut.-Col. S. C. Guilan, T.D., Editor of the Institute of Metals, was appointed also Assistant Secretary of that Institute on his return from active service. Mr. Chattin then reverted to his former position of Assistant Secretary of the Iron and Steel Institute, continuing to serve also as Executive Editor to the end of the year, when he became Technical Editor.

Lieut.-Col. A. Post was appointed general assistant on 25th March, 1946. Mr. E. R. Mort became Managing Editor on 1st August and Mr. C. R. Harman Assistant Editor on 1st November. Dr. M. A. Vernon was appointed Information Officer on 1st June, and Dr. N. Stuart, who had been giving part-time service since 19th March, became whole-time Education Officer as from 1st January, 1947. The staff was further strengthened by other appointments.

The Council wish to record their appreciation of the services rendered by all members of the staff.

METALLURGICAL SOCIETIES JOINT PENSION SCHEME

The Council have approved that the Institute, in association with the Institute of Metals and the Institution of Metallurgists, form the Metallurgical Societies Joint Pension Scheme, to come into force on 1st January, 1947. Present members of the staffs of the three societies will be entitled, and future full-time permanent members of the staffs will be required, to join this contributory pension scheme which, in the Council's opinion, will adequately meet the Institute's responsibilities to its employees in respect of pensions.

HONOURS CONFERRED ON MEMBERS

(Up to 13th March, 1947)

The Council tender their warm congratulations to the following Members of the Institute for honours and appointments received during the period under review:

- AUSTIN, Dr. C. R.—Awarded the Henry Marion Howe Medal of the American Society for Metals for 1946.
- BAIN, E. C.—Awarded the Albert Sauveur Achievement Award for 1946.
- BALFOUR, The Hon. R. A.—Elected Master of the Company of Cutlers in Hallamshire.
- CHEVENARD, PIERRE—Elected a Member of the French Academy of Sciences.
- DAVIES, T. E.—Created an Officer of the Order of the British Empire.
- DESCH, Dr. C. H., F.R.S.—Elected an Honorary Member of the American Institute of Mining and Metallurgical Engineers.
- FETZER, Dr. M. C.—Awarded the Henry Marion Howe Medal of the American Society for Metals for 1946.
- GAYLER, Dr. MARIE L. (Mrs. HAUGHTON)—Awarded the Institute of Metals Platinum Medal for 1947.
- GILL, C. S.—Elected President of the Tees-side Chamber of Commerce. Re-elected Chairman of the British Steel Founders Association for 1947.
- GILL, J. P.—Awarded an Honorary Degree of Doctor of Engineering by the University of Missouri.
- GREGORY, Dr. E.—Elected President of the Institution of Engineering Inspection.
- GRIFFITHS, Dr. W. T.—Created a Knight Bachelor.
- HACKING, R. A.—Appointed an Officer of the Order of the British Empire.
- HAUGHTON, Dr. J. L.—Awarded the Institute of Metals Platinum Medal for 1947.
- JEFFRIES, Dr. ZAY—Awarded the John Fritz Medal of the American Institute of Mining and Metallurgical Engineers for 1946.
- JENKIN, Dr. J. W.—Elected President of the Institution of Metallurgists.
- JONES, Sir WALTER BENTON, Bt.—Elected President of the British Tar Federation.
- JONES, Dr. W. D.—Awarded the Stevens Institute of Technology Medal.
- KIRKBY, R. A.—Elected President of the Refractories Association of Great Britain for 1946-47.
- LARKE, Sir WILLIAM, K.B.E.—Elected President of the British Welding Research Association; also President of the Society of British Gas Industries.
- LATHAM, G. H.—Appointed Chairman of the National Association for Rolled and Re-rolled Steel Products. Invited to be a member of the Iron and Steel Board.
- LATHE, F. E.—Created an Officer of the Order of the British Empire.
- LEEK, A. E.—Created a Member of the Order of the British Empire.
- MCGOWAN, Rt. Hon. Lord, K.B.E., D.C.L., LL.D.—Accepted Presidency of the Coal Trade Benevolent Association.
- MATHER, R.—Invited to be a member of the Iron and Steel Board.
- MOWILLIAM, J. A.—Awarded the Hatfield Prize by the Sheffield Metallurgical Association for the best paper of the year.

OWEN, A. G. B.—Created an Officer of the Order of the British Empire.

PATERSON, CLIFFORD C., O.B.E., F.R.S.—Created a Knight Bachelor. Elected President of the Institution of Engineers-in-Charge.

PENDRED, LOUGHNAN ST. L.—Made a Fellow of the City and Guilds of London Institute.

PFEL, Dr. L. B.—Appointed an Officer of the Order of the British Empire.

RIDGE, C. W.—Created an Officer of the Order of the British Empire.

RIVERDALE, Rt. Hon. Lord, LL.D., G.B.E.—Appointed First President of the Production Engineering Research Association.

ROSEVERE, Major G. R.—Created a Member of the Order of the British Empire.

RUSSELL, T. F.—Elected President of the Sheffield Metallurgical Association.

SANKEY, Col. H. B., C.B.E.—Appointed Sheriff of the County of Staffordshire.

SARJANT, Dr. R. J., O.B.E.—Appointed to the Chair of Fuel Technology, Sheffield University.

VERNON, Dr. W. H. J.—Appointed an Officer of the Order of the British Empire.

WHEELER, C. R.—Appointed a Commander of the Order of the British Empire.

WILLIAMS, CLYDE—Renominated President of the American Institute of Mining and Metallurgical Engineers.

WILSON, P. H.—Created an Officer of the Order of the British Empire.

WORNER, Dr. H. K.—Appointed Professor of Metallurgy in the University of Melbourne.

APPOINTMENT OF REPRESENTATIVES

The following is a list of the Institute's representatives at 31st March, 1947 :

BRITISH CAST IRON RESEARCH ASSOCIATION : Professor T. Turner.

BRITISH CORPORATION REGISTER OF SHIPPING AND AIRCRAFT, Technical Committee : Dr. A. McCance, F.R.S.

BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCIATION,
Sub-Committee J/E, Joint Committee, Steels for High Temperatures : Dr. J. W. Jenkin; *one appointment open.*
Sub-Committee F/J, Earthing to Water Mains : Dr. J. C. Hudson.

BRITISH IRON AND STEEL FEDERATION,
Statistical Committee : Mr. K. Headlam-Morley.
Films Panel : Mr. K. Headlam-Morley.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION,
Council : Professor J. H. Andrew, Professor G. Wesley Austin, Mr. Arthur Dorman, Mr. J. Sinclair Kerr, Dr. J. W. Jenkin, Dr. E. Gregory, Sir William Griffiths, D.Sc., The Hon. R. G. Lyttelton, Dr. W. J. Rees.

BRITISH REFRACTORIES RESEARCH ASSOCIATION,
Council : Mr. J. Sinclair Kerr.

BRITISH STANDARDS INSTITUTION,
General Council and Executive Committee : Mr. J. R. Beard (representing the Founder Institutions).
Chemical Engineering Divisional Council : Mr. E. F. Law.
Engineering Divisional Council E/- : The Hon. R. G. Lyttelton, Mr. J. Sinclair Kerr, Mr. W. B. Baxter.

Sub-Committee C/25/10, Painting of Iron and Steel : Mr. F. Fancutt, Mr. R. A. Hacking.

Technical Committee CEB/1, Cement : Mr. W. J. Brooke.

Sub-Committee CEB/6/1, Concrete Blocks : Mr. W. J. Brooke.

Technical Committee CH/17, Symbols used in Diagrams of Chemical Engineering Plant : Mr. A. E. Chattin.

Sub-Committee CH/18/2, Metallic Finishes : Mr. T. W. Whiting.

Sub-Committee CH/18/4, Phosphate Coatings : Dr. J. C. Hudson.

Technical Committee EL/28, Fans : Mr. A. F. Webber, Dr. A. M. Burdon.

Technical Committee HIB/15, Pressed Steel Galvanized Rainwater Goods : Dr. A. M. Burdon.

Iron and Steel Industry Committee IS/- : Mr. F. H. Saniter.

Technical Committee IS/-/1, Advisory Committee on Iron and Steel : Mr. F. H. Saniter.

Technical Committee IS/1, Co-ordination of Iron and Steel Specifications : Mr. S. Barracough.

Technical Committee IS/6, Steel Castings : Dr. R. H. Greaves.

Technical Committee IS/8, Creep Properties : Mr. L. Rotherham.

Technical Committee IS/11, Galvanized Corrugated Steel Sheets : Dr. J. C. Hudson.

Technical Committee IS/15, Iron and Steel for Shipbuilding : Sir Edward J. George.

Technical Committee IS/17, Cast Iron Columns for Street Lighting : Mr. J. G. Pearce.

Technical Committee IS/28, Protective Coatings for Iron and Steel : Dr. J. C. Hudson.

Technical Committee IS/29, Tinplate : Mr. D. Luther Phillips.

Technical Committee IS/35, Cast Iron : Mr. J. G. Pearce.

Sub-Committee IS/35/3, Malleable Steel Castings : Mr. C. H. Kain.

Technical Committee ISE/32, Iron and Steel Terms and Definitions : Mr. A. J. K. Honeyman.

Technical Committee ME/23, Indentation Hardness Testing : Mr. J. Woolman.

Technical Committee ME/25, Testing of Metal Sheets and Strip : Dr. A. M. Burdon.

Technical Committee ME/32, Engineering Symbols and Abbreviations : Dr. A. M. Burdon.

Technical Committee PAM/160, Reels and Drums for Electrical Wires : Dr. A. M. Burdon.

Technical Committee PSM/2, Welders' Goggles : Dr. C. H. Desch, F.R.S.

Solid Fuel Industry Committee, SF/- : Mr. A. F. Webber.

Technical Committee SF/1, Nomenclature and Definitions : Mr. A. F. Webber.

Technical Committee SF/2, Underfed Screw Type Stokers : Mr. A. F. Webber.

Technical Committee SF/4, Heating Stoves : Mr. A. F. Webber.

Technical Committee SF/17, Sampling and Analysis of Flue Gases : Mr. F. A. Gray.

Units and Technical Data Co-ordinating Committee : Sir Wm. Larke, K.B.E.

Conference M/4, Letter Symbols : Dr. A. M. Burdon.

CITY AND GUILDS OF LONDON INSTITUTE, Advisory Committee on Metallurgy : Dr. J. W. Jenkin.

CLEVELAND INSTITUTION OF ENGINEERS, Council :
Mr. Arthur Dorman.

CONSTANTINE COLLEGE, Advisory Committee : Mr.
E. W. Jackson.

EMPIRE COUNCIL OF MINING AND METALLURGICAL
INSTITUTIONS : Mr. K. Headlam-Morley, Mr. J.
Sinclair Kerr.

ENGINEERING PUBLIC RELATIONS COMMITTEE,
Main Committee : *appointment open*.

Executive Committee : Mr. K. Headlam-Morley.

HATFIELD MEMORIAL LECTURE COMMITTEE : Mr. K.
Headlam-Morley, Dr. C. Sykes, F.R.S.

HONG-KONG UNIVERSITY, Home Committee : *appoint-
ment open*.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY,
Board of Governors : Dr. C. H. Desch, F.R.S.

IMPERIAL INSTITUTE, Mineral Resources Department,
Iron and Ferro-Alloy Metals Committee : Mr. K.
Headlam-Morley.

INSTITUTE OF FUEL, Council : Professor R. J. Sarjant.

INSTITUTE OF PHYSICS, Industrial Radiology Group,
Sub-Committee on Terminology relating to
Casting Defects revealed by X-Rays : Dr. R.
Jackson.

INSTITUTE OF WELDING,
Council and Representative of Patron Institutions :
Mr. K. Headlam-Morley.

Joint Library Committee (with British Welding
Research Association) : Mr. K. Headlam-Morley.

INSTITUTION OF CIVIL ENGINEERS, Committee on Soil
Corrosion of Metals and Cement Products, Sub-
Committee on Soil Corrosion of Metals : Dr. J. C.
Hudson.

INSTITUTION OF MECHANICAL ENGINEERS, Research
Committee on High-Duty Cast Irons for General
Engineering Purposes : Dr. J. E. Hurst.

INSTITUTION OF METALLURGISTS, Council : Mr. H. H.
Burton, Mr. J. Sinclair Kerr.

JOINT COMMITTEE ON MATERIALS AND THEIR TESTING :
Mr. K. Headlam-Morley.

JOINT COMMITTEE ON METALLURGICAL EDUCATION :
Dr. C. H. Desch, F.R.S., Mr. R. A. Hacking,
The Hon. R. G. Lyttelton.

LIVERPOOL UNIVERSITY, Court of Governors : Sir W.
Peter Rylands, Bt.

KING'S COLLEGE, NEWCASTLE-UPON-TYNE (University
of Durham), Metallurgy Advisory Committee :
Mr. J. H. Patchett.

LEEDS METALLURGICAL SOCIETY, Council : Mr. A.
Preece.

LINCOLNSHIRE IRON AND STEEL INSTITUTE, Council :
Mr. W. B. Baxter.

LLOYD'S REGISTER OF SHIPPING, Technical Commit-
tee : Mr. H. H. Burton.

NATIONAL CERTIFICATES IN METALLURGY JOINT
COMMITTEE : Mr. R. A. Hacking, Dr. J. W. Jenkin.

NATIONAL PHYSICAL LABORATORY, General Board :
Professor J. H. Andrew, Mr. H. H. Burton.

NEWPORT AND DISTRICT METALLURGICAL SOCIETY,
Council : Mr. G. H. Latham.

PARLIAMENTARY AND SCIENTIFIC COMMITTEE : Mr. K.
Headlam-Morley.

RAMSAY MEMORIAL LABORATORY, Advisory Commit-
tee : *appointment open*.

ROYAL SCHOOL OF MINES, Advisory Board : Mr.
Vernon Harbord.

ROYAL SOCIETY, General Board for Administering
Government Grants for Scientific Investigations :
The President.

SCHOOL OF METALLIFEROUS MINING (CORNWALL),
Board of Governors : Mr. J. S. Hollings, C.B.E.

SCIENCE MUSEUM, Advisory Council : *appointment
open*.

SHEFFIELD SOCIETY OF ENGINEERS AND METAL-
LURGISTS, Council : Professor J. H. Andrew.

SHEFFIELD UNIVERSITY, Court of Governors : Sir
Arthur B. Winder.

STAFFORDSHIRE IRON AND STEEL INSTITUTE, Council :
Dr. J. E. Hurst.

SWANSEA AND DISTRICT METALLURGICAL SOCIETY,
Council : Captain H. Leighton Davies, C.B.E.

WORSHIPFUL COMPANY OF BLACKSMITHS, Court of
Assistants : Dr. C. H. Desch, F.R.S., the Hon.
R. G. Lyttelton.

FINANCE

(The Accounts for 1946 are appended)

The accounts for the year ended 31st December, 1946, reflect the increased activity that has become possible with the return of peace ; income and expenditure have both risen substantially.

During the six years from 1st January, 1940, to 31st December, 1945, Capital, Reserve, and Suspense Accounts were increased by over £10,000. During 1946 there was a reduction of about £2,500 and the Council contemplate further reductions during the next two years. This is necessary to finance the new activities referred to elsewhere in this Report, including the monthly *Journal*, reorganization of the Library and Information Departments, and the Engineers Group ; reference is also made to the new staff which has been appointed to do this work and to the new arrangements for providing pensions. It is anticipated that these extended activities will, when fully established, result in an increase in income sufficient to meet the full annual cost. Some of the work is being done for the British Iron and Steel Research Association in accordance with the arrangement for co-operation referred to in this Report. The accounts show the substantial contribution towards the cost which is being made by the Research Association, and the Council wish to take this opportunity of expressing their appreciation of the friendly spirit in which the negotiations were conducted.

The audited accounts are presented in the usual form, but in addition there are included, for the first time, departmental accounts designed to show more clearly the income and expenditure on Library and Information Departments, publishing, and general activities, as well as allocation of the grant paid by the Research Association and the extent to which various work is being financed from the general income of the Institute.

General Fund : Income and Expenditure Account—Income has increased by £8,721 to £31,300, expenditure by £12,889 to £35,053, and there is carried over to the Balance Sheet a deficit of £3,753.

The increase of £1,930 to £10,181 in income from Annual Subscriptions reflects the substantial growth in membership; the full benefit of this will not be experienced until the following year. Sales of publications have risen by £2,897 to £4,766; this is partly due to an increase in the number of volumes disposed of, partly to a revision in the selling prices, and partly to taking in income from orders booked for volumes to be issued in respect of 1946 but not actually published before the end of the year; the full cost of printing these has been included under expenditure as explained below. The sale of translations has realized £679. The grant from the British Iron and Steel Research Association has risen by £4,453 to £8,703; this sum is arrived at by charging half the remaining deficit after payment of a block grant of £5,000 and before making a transfer of £50 to the Suspense Account for the Ten Years Index. The work on which the grant has been spent is shown in the new departmental accounts. Income from Companies' Special Subscriptions has dropped by £579 to £4,093 as anticipated owing to most of the seven-year covenants, on which refund of Income Tax was obtained, having come to an end.

Most items of expenditure have increased. This is due partly to the rise in costs and partly to the new work and greater activity that have already been mentioned. Further information on the allocation of expenditure to different aspects of the Institute's work is given in the departmental accounts. Salaries, after deducting the usual contributions from the Carnegie Research Fund and the payments made by the Joint Committees on Metallurgical Education and National Certificates, have increased by £4,954 to £13,137; there will be a further increase this year. The substantial rise in expenditure on Repairs and Decorations (by £211 to £353), Office Furniture (by £797 to £981), and Library Books and Binding (£442 to £733) shows that the Institute has been successful in making good some of the arrears of the war years. Publishing expenses have more than doubled—an increase of £5,297 to £9,762; details are given in the departmental accounts. This is due to the large amount of material published, to the greater circulation required by the growth in membership, to the very heavy rise in printing costs, and to the inclusion of what is believed to be sufficient provision to cover the full cost of all publications due to be issued in

respect of 1946, including the final volume of the *Journal* for that year and several Special Reports, the cost of which would normally have been carried forward to the subsequent year. This has been done so that the cost of the new monthly *Journal* and other publications which will accompany it may in future be clearly shown. Translations have cost £300, a reduction of £113.

The increases in expenditure on Stationery and Printing (by £888 to £1,918), Postage and Receipt Stamps (by £159 to £829), Travelling and Entertainment (by £77 to £796), Meetings (by £412 to £559), and Grants to Local Societies (by £41 to £123) reflect partly the increase in activity and partly the very heavy rises in costs. £50 has been transferred to the Reserve Fund for the Ten Year Index. Other items do not appear to require comment.

General Fund : Balance Sheet—The Excess of Expenditure over Income for the year (£3,753) transferred from the Income and Expenditure Account, has been met in part by transfers of £500 each from the Library Suspense Account and the General Reserve with the result that the Accumulated Excess of Income over Expenditure is reduced from £2,967 to £214. The Entrance Fees and Life Composition Reserve Funds have been increased by £965 and £193 respectively.

The substantial rise in the amount owing to Sundry Creditors (by £9,292 to £12,705) is due almost entirely to the policy previously referred to of including in these accounts provision for all publishing expenses estimated to be incurred on publications due to be issued in respect of 1946 and earlier years. This accounts for £11,132, an increase of £8,715. There is only a relatively small increase (by £2,110 to £2,321) in the corresponding figure among the Sundry Debtors (total increase of £746 to £2,778) on the Assets side because credit has been taken only for actual sales and orders received.

As usual no value has been placed on Subscriptions in Arrears, the Stock of *Journals*, and Office Furniture and Library. Investments have increased by £2,200 to £38,612 and their Market Value at the end of the year was £7,495 greater.

Trust Funds—The Balance Sheets and Income and Expenditure Accounts of the Trust Funds have been prepared in the usual form.

Andrew Carnegie Research Fund—As no Research Grants were paid, it was possible to add £500 to the General Reserve, which now stands at £2,000, and £612 to Accumulated Excess of

Income over Expenditure, making a total of £6,368 to be added to the Capital Fund of £25,682. The Market Value of the Investments at 31st December, 1946, exceeded by £9,037 their cost price of £32,185, at which they are taken into the Balance Sheet.

Williams Prize Fund—Williams Prizes to the value of £150 were awarded, resulting in an Excess of Expenditure over Income of £26 and a corresponding reduction in the Accumulated Balance to £643. The Fund is invested in 3½% Conversion Loan valued at cost price £2,670; the Market Value at the date of the Balance Sheet was £1,301 greater (£3,971).

Bessemer Medal Fund—The value of the Bessemer Medal Fund invested in 4% L.M.S.R. Debenture Stock was £62 above the nominal value of £400.

House Fund and Industrial Subscriptions—Income from special subscriptions was £4,093. The Council acknowledge with thanks receipt of separate subscriptions from Colvilles, Ltd., and Wm. Beardmore & Co., Ltd., whose subscriptions have hitherto been combined.

They wish to take this opportunity of again expressing their thanks to the following subscribers:

Edgar Allen & Co., Ltd.
Ashmore, Benson, Pease & Co., Ltd.
Babcock and Wilcox, Ltd.
Bairds and Scottish Steel, Ltd.
Baldwins, Ltd.
Arthur Balfour & Co., Ltd.
Frederick Braby & Co., Ltd.
Bradley and Foster, Ltd.
The Briton Ferry Steel Co., Ltd.
Broken Hill Proprietary Co., Ltd.
Burnell & Co., Ltd.
Bynea Steel Works, Ltd.
Consett Iron Co., Ltd.
The Darlington Forge, Ltd.
The Darwen and Mostyn Iron Co., Ltd.
Darwins, Ltd.
Davy and United Engineering Co., Ltd.
Dorman, Long & Co., Ltd.
English Steel Corporation, Ltd.
Thos. Firth and John Brown, Ltd.
General Refractories, Ltd.
Gillette Industries, Ltd.
Guest Keen Baldwins Iron and Steel Co., Ltd.
Guest Keen and Nettlefolds, Ltd.
J. J. Habershon & Sons, Ltd.
Hadfields, Ltd.

Head Wrightson & Co., Ltd.
N. Hingley & Sons, Ltd.
William Jessop & Sons, Ltd.
Kayser, Ellison & Co., Ltd.
The Kennedy Press, Ltd.
The Kettering Iron and Steel Co., Ltd.
The Lancashire Steel Corporation, Ltd.
The Llanelly Steel Co. (1907), Ltd.
John Lysaght, Ltd.
McCall & Co. (Sheffield), Ltd.
The Millom and Askam Hematite Iron Co., Ltd.
The Mond Nickel Co., Ltd.
Neepsend Steel and Tool Corporation, Ltd.
Newton Chambers & Co., Ltd.
Samuel Osborn & Co., Ltd.
The Oughtibridge Silica Firebrick Co., Ltd.
The Park Gate Iron and Steel Co., Ltd.
Partridge Jones and John Paton, Ltd.
The Patent Shaft and Axletree Co., Ltd.
Raine & Co., Ltd.
Round Oak Steel Works, Ltd.
Simon-Carves, Ltd.
Skinningrove Iron Co., Ltd.
Walter Somers, Ltd.
The South African Iron and Steel Industrial Corporation, Ltd.
South Durham Steel and Iron Co., Ltd.
South Wales Siemens Steel Association.
The Stanton Ironworks Co., Ltd.
The Steeley Co., Ltd.
John G. Stein & Co., Ltd.
Stewarts and Lloyds, Ltd.
John Summers & Sons, Ltd.
Tata, Ltd.
Taylor Bros. & Co., Ltd.
Richard, Thomas and Baldwins, Ltd.
The Union Steel Corporation (of South Africa), Ltd.
The United Steel Companies, Ltd.
Vickers, Ltd.
The Wellman Smith Owen Engineering Corporation, Ltd.
The Welsh Plate and Sheet Manufacturers' Association.
Whitehead Iron and Steel Co., Ltd.
The Woodall-Duckham Vertical Retort and Oven Construction Co. (1920), Ltd.

Many of the above companies subscribed originally for a period of seven years, ending in 1945, 1946, or 1947. Most have acceded to the Council's request to continue payment for a further three years in order to enable the re-organization of the Institute's finances and activities, which was interrupted by the war, to be completed.

STATEMENT OF ACCOUNTS FOR 1946

THE IRON AND STEEL INSTITUTE
BALANCE SHEET, 31st DECEMBER, 1946

[illegible]

We have examined the above Balance Sheet of the Institute and certify it to be correct.
FINSBURY CIRCUS HOUSE.

11, STREET,
LONDON, E.C.2.
March 5th, 1947.

(Signed) W. B. KEEN & Co.,
Chartered Accountants

INCOME		EXPENDITURE	
1945	1946	1945	1946
£	£	£	£
Entrance Fees	£492	Salaries	£13,937
Do. Companies' Nominations	473	Less Contributions from Carnegie Research Fund	£150
Less Transfer to Reserve Fund	965	Joint Committee on Metallurgical Education	200
	965	National Certificates Committee	450
Annual Subscriptions :—			800
Members, Home Current	6,392	National Insurance	13,137
Do. Companies' Nominations	658	Staff Superannuation Fund	145
Do. Arrears	223	Office Rent	311
	7,273	Repairs and Decorations	1,200
Members, Overseas Current	1,770	Cleaning, Heating, Lighting and Water	353
Do. Companies' Nominations	38	Library Books and Binding	1,161
Do. Arrears	459	Publishing Expenses :—	733
	2,306	Printing and Postage	9,762
Associates, Current	501	B.I.S.R.A. Publications	£4,380
Do. Companies' Nominations	84	Less Receivable	4,380
Do. Arrears	17		—
	602	Translations Service	9,762
Sales of Publications :—		Office Furniture	300
Journals, Special Reports, etc.	4,552	Stationery and Printing	981
Bulletin	214	Postage and Receipt Stamps	1,918
	4,766	Travelling and Entertainment Expenses	829
Translations	679	Insurance	796
Interest on Investments (Gross) :—		Do. War Damage	71
General Fund	1,311	Telephone Rental and Calls	300
Life Composition Fund	141	Office Disbursements and Sundry Expenses	161
Bessener Medal Fund	16	Meetings	559
	1,468	Affiliated Local Societies	123
Interest on Deposit Account	56	Bessener Gold Medal	—
Sundry Receipts	104	Institution of Metallurgists	—
Institute of Metals :—		National Certificates Committee :—	
Rent Receivable	750	Contribution	300
Contribution to Joint Library	500	Prize Fund	200
	1,250		500
British Iron and Steel Research Association :—		Joint Committee on Metallurgical Education	25
Grant	8,703	Grants :—	
Balance, being Excess of Expenditure over Income carried down	6,543	British Electrical and Allied Industries Research Association	—
		British Refractories Research Association	25
		Joint Committee on Materials and their Testing	1
		British Standards Institution	50
		Mellor Memorial Fund	10
		Sheffield University Foundry Prize	11
		Parliamentary and Scientific Committee	11
		Sundry Researches	225
		Auditors' Fees for 1945	333
			52
£20,256	£33,730		£33,750
£	£		£
Special Subscriptions :—		Balance brought down	—
Contributions received during 1946	3,856	Transfer Reserve and Suspense Accounts :—	
Income Tax Recoverable	237	Repairs and Decorations	—
	4,093	Library	—
Balance, being Excess of Expenditure over Income	3,753	Ten-Year Index	50
		General Reserve	—
		Bessener Gold Medal	—
			50
		Companies' Nominations :—	
		Entrance Fees	473
		Subscriptions Account :—	
		Home Members	£658
		Overseas Members	38
		Associates	84
			780
		Balance, being Excess of Income over Expenditure	1,253
			—
£4,672	£7,846		£7,846

THE IRON AND STEEL INSTITUTE

SCHEDULE OF INVESTMENTS AT 31st DECEMBER, 1946,
SHOWING NOMINAL VALUES, COST VALUES AND PRESENT MARKET VALUES

Nominal Value	Nature of Security	Market Value, 31st December, 1946	Cost Value
GENERAL FUNDS OF THE INSTITUTE			
£ s. d.		£	£
2,197 7 0	3½% War Stock	2,373	2,161
1,324 7 4	3½% Conversion Loan	1,523	1,254
447 0 0	Southern Railway 4% Debenture Stock	1,844	449
1,872 0 0	London & N. Eastern Railway 4% 2nd Guaranteed Stock	2,342	2,150
2,241 0 0	Do. do. 4% 1st do.	2,609	2,432
2,649 4 0	2½% Consolidated Stock	1,252	1,800
1,500 0 0	Buenos Ayres Great Southern Railway 4% Debenture Stock	3,441	1,595
2,954 1 0	4% Consolidated Stock	437	3,176
437 0 0	London & N. Eastern Railway 3% Debenture Stock	14,845	376
12,242 19 3	4% Funding Loan 1960/90	2,000	9,512
2,000 0 0	3% Defence Bonds (P.O. Register)	2,000	2,000
2,000 0 0	3% Savings Bonds, 1955/65	2,170	2,000
2,000 0 0	Do. 1960/70	2,185	2,000
1,500 0 0	Do. 1965/75	1,661	1,500
2,018 14 6	3% Local Loans	2,019	2,000
		<u>£41,262</u>	<u>£34,405</u>

LIFE COMPOSITION FUND

587 13 10	3½% Conversion Loan	676	513
493 4 4	3% Local Loans	493	467
1,330 0 0	London & N. Eastern Railway 3% Debenture Stock	1,330	1,255
594 0 0	London Passenger Transport Board 4½% "A" Stock	769	638
205 15 6	3½% War Stock	222	212
681 13 0	4% Funding Loan	827	600
196 10 1	Do.	238	231
		<u>£4,555</u>	<u>£3,916</u>

WILLIAMS PRIZE FUND

(Trustees : Sir Wm. Larke, K.B.E., The Hon. R. G. Lyttelton and N. H. Rollason.)

3,452 15 7	3½% Conversion Loan	<u>£3,971</u>	<u>£2,670</u>
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ANDREW CARNEGIE RESEARCH FUND

(Trustees : Sir Wm. Larke, K.B.E., The Hon. R. G. Lyttelton and N. H. Rollason.)

6,897 14 11	3½% War Stock	7,449	6,896
800 0 0	Do.	864	794
2,693 12 0	3½% Conversion Loan	3,098	2,007
2,642 12 0	3% Local Loans	2,643	2,527
1,750 0 0	North Eastern Electric Supply Co. 3½% Consolidated Debenture Stock	1,759	1,762
1,500 0 0	Great Western Railway 4% Debenture Stock	1,882	1,204
2,000 0 0	London, Midland & Scottish Railway 4% Debenture Stock	2,310	1,693
1,312 0 0	London & N. Eastern Railway 4% 1st Guaranteed Stock	1,371	881
5,000 0 0	Do. 4% Debenture Stock	5,775	3,540
6,000 0 0	Do. 3% Debenture Stock	6,000	3,545
1,000 0 0	3% Savings Bonds, 1955/65	1,085	1,000
2,250 0 0	Do. 1960/70	2,458	2,250
2,813 2 7	2½% Consolidated Stock	2,771	2,339
1,250 0 0	3% Defence Bonds	1,250	1,250
500 0 0	2½% Do.	500	500
		<u>£41,215</u>	<u>£32,188</u>

SIR ROBERT HADFIELD LEGACY

267 11 2	3% Savings Bonds, 1955/65	<u>£290</u>	<u>£268</u>
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BESSEMER MEDAL FUND

(Trustees : Desmond Lysaght, The Hon. R. G. Lyttelton and N. H. Rollason.)

400 0 0	London, Midland & Scottish Railway 4% Debenture Stock	<u>£462</u>	<u>—</u>
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(Signed) R. G. LYTTELTON,
Hon. Treasurer.(Signed) K. HEADLAM-MORLEY,
Secretary.

We have examined the foregoing Balance Sheets and Income and Expenditure Accounts with the Books and Vouchers of the Institute and certify them to be correct. We have also verified the balances at the Bankers and the Securities for the Investments shown above.

FINSBURY CIRCUS HOUSE,
BLOMFIELD STREET, E.C.2.
March 4th, 1947.

(Signed) W. B. KEEN & Co.,
Chartered Accountants.

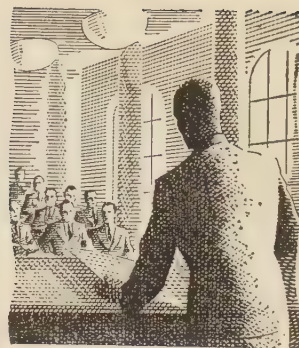
STATEMENT OF ACCOUNTS FOR 1946

DEPARTMENTAL ACCOUNTS
FOR THE YEAR ENDED 31ST DECEMBER, 1946

INCOME				EXPENDITURE			
	General Activities	Publishing	Library and Information		General Activities	Publishing	Library and Information
	£	£	£		£	£	£
Subscriptions..	10,181	—	10,181	Salaries : Direct	—	3,453	2,601
Interest	1,524	—	1,524	Indirect	—	1,592	381
Sundry Receipts	104	—	104	National Insurance	5,110	5,045	2,982
Special Subscriptions	4,093	—	—	Staff Superannuation Fund	77	97	28
Less Companies' Nominations—Transfer for Index (£50)	1,303	—	—	Travelling and Entertainment Expenses	119	—	95
B.I.S.R.A. Grant	1,203	—	—	Meetings	796	—	796
Joint Research Committees	2,000	—	—	Affiliated Local Societies	123	—	559
Publishing	—	2,000	—	National Certificates Committee	500	—	500
Abstracts	—	1,000	—	Joint Committee on Metallurgical Education	25	—	25
Information Services	—	3,000	—	Grants	333	—	333
Institute of Metals : Rent Receivable	300	285	2,500	Rent, Repairs, etc., Cleaning, etc., Furniture, Stationery, etc., Postage, etc., Telephone, Disbursements, Audit	2,810	2,670	1,546
Do. Library	—	—	500	Library Books and Binding	—	—	733
Sales of Publications :—	—	—	—	Publishing Expenses :—	—	—	—
Journals : 1945 No. 1 and earlier	2,164	—	—	Journal : Printing and Paper : 1945 : Vol. No. 1 (Balance)	425	—	—
1945 No. 2	610	—	—	1946 : Vol. No. 1 (Provision)	1,381	—	—
1946 No. 1	607	—	—	1946 : Vol. No. 1 {	1,480	—	—
1946 No. 2	608	—	—	Vol. No. 2 {	1,580	—	—
Miscellaneous	—	3,989	—	Postage	359	—	—
Bulletin	82	—	—	Miscellaneous	166	5,391	—
Special Reports	214	—	—	Advance Copies : Printing and Paper	1,018	—	—
Bibliographies	460	—	—	Postage	181	—	—
Translations	21	777	—	Bulletin (1946) : Printing and Paper	815	1,199	—
	—	679	679	Postage	83	898	—
	—	—	—	Special Reports : Printing and Paper : No. 31	274	—	—
	—	—	—	Nos. 33, 35 and 37 (Provision)	2,000	2,274	—
	—	—	—	Less Receivable	4,380	—	—
	—	—	—	Translations Service	—	300	—
	—	—	—	Cr. Balance	7,650	—	—
Dr. Balances	—	9,184	2,219		18,102	17,914	5,384
	18,102	17,914	5,384	Dr. Balance from Publishing and Library Accounts .....	...	...	...
Cr. Balance from General Activities .....	...	...	...		...	...	...
Balance, being Excess of Expenditure over Income .....	...	...	...		...	...	...
	£52,803	£52,803	£52,803				

IRON AND STEEL INSTITUTE PAPERS

PLANT DESIGN • MANUFACTURE • RESEARCH • DEVELOPMENT



Abnormal Creep in Carbon Steels*

By J. Glen, B.Sc., A.R.T.C., A.I.M.†

SYNOPSIS

Short-time creep tests at a stress of 8 tons/sq. in. and a temperature of 450° C., have been carried out on a series of low-carbon steels containing 0.4–1.5% of manganese, 0.01–0.15% of silicon, and 0–0.11% of molybdenum, and with varying amounts of aluminium up to 3 lb./ton.

It is shown that manganese, silicon, and molybdenum within the limits examined reduce the creep rate and that the abnormal creep resulting from aluminium additions is reduced considerably by these elements.

In production casts of basic open-hearth steel it is shown that, with proper control, aluminium may be used as a deoxidizer, provided that the steel remains coarse-grained as measured by the McQuaid-Ehn test.

INTRODUCTION

A STUDY of the voluminous literature on creep shows that there are many aspects of the subject still awaiting clarification. Correlation of the work of many of the investigators in this field is extremely difficult, if not impossible, not only because of the different methods of testing employed, but also because in so many cases no cognisance has been taken of the effect of manufacturing conditions, such as the deoxidation practice, heat-treatment, and the presence of residual alloying elements.

In order that the influence of the various factors involved may be properly appreciated, it is proposed to discuss briefly creep data published by Bailey¹ for a 0.40% carbon steel, and by Tapsell² for three lower-carbon steels in the form of a steam pipe, a superheater header, and a superheater tube. Such data, presented as the stress/temperature relationship for a specific amount of deformation in a given time, are derived from creep tests of long duration and may

be regarded as the most reliable and satisfactory available. Particulars of the steels and the results obtained are given in Table I and Fig. 1 respectively.

It will be observed that steels 75 and 35 give results of the same order. The 0.40% carbon steel, while being better at low temperatures (below 800° F., approximately), is inferior at higher temperatures. Steel 52, on the other hand, is in quite a different class, being much inferior to any of the other steels.

The essential difference between steel 52 and the other steels was that it had a low silicon content and had been deoxidized with approximately 2 lb. of aluminium per ton added to the ladle, and it is now well known that minor differences in deoxidation practice may have a pronounced effect on creep. Recent American work, for example, on carbon steels, confirms the adverse

* Received 19th August, 1946.

† Research Dept., Messrs. Colvilles, Ltd., Motherwell.

TABLE I—Particulars of Steels Used in Previous Tests

Type of Steel	Dimensions of Tube		Condition	Analysis				
	Outside Dia., in.	Wall Thickness, in.		C, %	Si, %	S, %	P, %	Mn, %
No. 75	12	1	Normalized, 900° C. ...	0.24	0.10	0.032	0.40	0.61
No. 35	10	$\frac{1}{2}$	Hot-rolled ...	0.135	0.18	0.037	0.28	0.47
No. 52	2	$\frac{3}{16}$	Hot-rolled ...	0.12	0.04	0.027	0.017	0.45
Forged bar (Bailey)	5	...	Normalized, 850°C., 2hr. at 550°C., A.C.	0.4	...	...	...	...

effect in this respect of excessive aluminium additions.

From a practical point of view it is fortunate that steels showing widely different creep characteristics in long-time tests can be differentiated by tests of relatively short duration, as was clearly demonstrated by Tapsell.² The test employed by

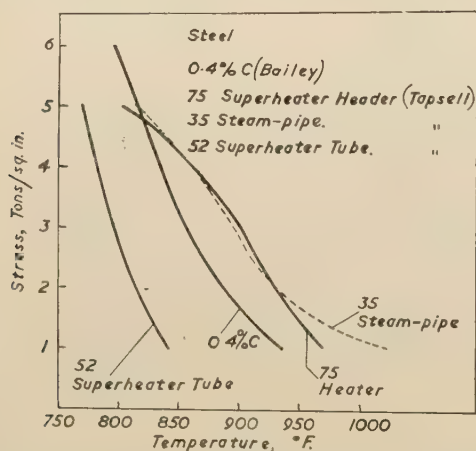


FIG. 1—Stress/temperature relationship for 0.1% creep strain in 100,000 hr.

Tapsell involved the determination of the time/strain curve over a period of 8 days, the test-piece carrying a constant load of 8 tons/sq. in. at a temperature of 450° C. Using this test Tapsell compared the three steels, Nos. 35, 52, and 75, the results being as follows :

CREEP RATE AT 8 DAYS (*in./in./hr. × 10⁶*)

Steel	As Received	Normalized
35	9.0 (hot-rolled)	10.0
75	2.2 (normalized)	...
52	81.0 (hot-rolled)	260.0

It will be observed that normalizing has further lowered the creep resistance of steel 52 to a very considerable extent, whereas steel 35 is hardly affected by this treatment.

The deterioration in creep characteristics due to differences in the amounts of aluminium and of silicon added as deoxidizers, will in future be

referred to as abnormal creep. The phenomenon appears to be related to the austenitic grain-size as measured by the McQuaid-Ehn test, fine-grained steels being those which show abnormal creep. This relationship may, however, be only indirect. It should also be clearly understood that the existence of abnormal creep depends not only on the deoxidation practice, but on the temperature of testing and on the thermal history of the test sample.

The problem of abnormal creep has an important bearing on the economics of production, particularly of tube-steel billets suitable for a rotary piercing process, since the elimination of aluminium in the deoxidation of this steel would create difficulties in bulk manufacture. Fortunately, however, as will be shown later, perfectly satisfactory creep properties can be obtained despite the use of aluminium, provided that the additions are intelligently controlled.

Reference has been made to the influence of austenitic grain-size on creep, but there is another aspect of the problem to be considered, namely, the influence of the existing or ferritic grain-size. It is generally accepted that a coarse ferritic grain-size improves creep resistance and this appears to be borne out by the fact that steels such as No. 52, showing abnormal creep, can be made normal in this respect by air-cooling from a temperature sufficiently high (approximately 1100° C.) to coarsen the structure. It should be noted, however, that the creep characteristics of these steels are not improved if the test-pieces are slowly cooled from the coarsening temperature, from which it may be concluded that ferritic grain-size *per se* is not the only determining factor. In fact, the influence of the ferritic grain-size on creep depends upon the type of steel, the method of deoxidation, the thermal history of the steel, and the temperature of testing.

In the foregoing discussion, emphasis has been laid on the problem of abnormal creep arising from deoxidation practice, and an attempt has been made, in the light of our present knowledge,

to point out some of the complexities and pitfalls which beset the path of the investigator. Unfortunately, the problem is further complicated by quite substantial variations in creep characteristics owing to variations in manganese, silicon, and residual elements, particularly molybdenum, such as are met with in ordinary mild steel. It is obvious, therefore, that any attempt at elucidating the mechanism involved should be preceded by a systematic investigation of these variables and the work described in this paper is a first step in this direction.

The first and greatest problem to be overcome was the choice of a suitably discriminating creep test. In view of the programme contemplated, a short-time test was inevitable, and since the main object was to examine the incidence of abnormal creep, it was decided to standardize as far as possible on Tapsell's test—8 tons/sq. in. at 450° C. with a duration of 5 days—to allow a fresh batch of specimens to be tested each week.

Bailey¹ was the first to demonstrate the effects of what he termed "thermal hardening," which consists of a stiffening of the steel due to thermal influences in the initial stages of creep. After a certain time, depending on the temperature, the effects of this thermal hardening are nullified, with a consequent increase in the creep rate. It is this phenomenon of thermal hardening, or ageing, followed by softening, which gives rise to the slight bulge in the stress/temperature curve of some of the steels shown in Fig. 1. The bulge is quite pronounced in the curves for steels 35 and 75 at a temperature of about 850–900° F. The 0.40% carbon steel shows the bulge very slightly at a somewhat lower range of temperature. Steel 52, on the other hand, shows no bulge at all. It is surprising that, apart from Bailey, no one appears to have realized the significance of this thermal hardening, an understanding of the mechanism of which, in the opinion of the author, provides the key to further development of creep-resisting steels. This phenomenon restricts the usefulness of a short-time creep test, and due cognisance has to be taken of it in interpreting the results obtained. Nevertheless, it was considered that the short-time test selected would provide data of a qualitative nature, at any rate, which would serve as a useful basis for comparing the steels. At the same time, such information is a necessary preliminary to a more comprehensive study of the subject.

RANGE OF STEELS TESTED

Since it was not practicable to explore all the possible variables, it was decided to confine the investigation to steels of one carbon content.

The evidence available seemed to demonstrate conclusively that low-carbon steels give the best creep properties, particularly low-carbon alloy steels. To be more precise, the lower carbon steels are better at the higher ranges of temperature, *i.e.*, at any particular temperature there is an optimum carbon content which will give the best creep resistance. Since the creep strength at higher temperatures is the most important, it was decided to fix the carbon content of the steel at 0.10–0.12%. This relates the present work to work in hand on alloy steels. Also, this carbon content is normal for superheater-tube steel, and it was known that this type of steel was most prone to show abnormally low creep.

With this carbon content, 57 steels were prepared containing no silicon, 0.05, 0.10, and 0.15% of silicon, with 0.4, 0.6, and 0.8% of manganese. To each of these series aluminium was added equivalent to 0, $\frac{1}{2}$, 1, $1\frac{1}{2}$, and 2 lb./ton. In addition, a further six steels were made with higher manganese contents.

Tests have also been included on two casts of basic open-hearth steel to which varying aluminium additions were made to each ingot, and on a series of basic open-hearth casts with varying grain-size.

MANUFACTURE OF STEELS

With the exception of the open-hearth casts, all the above steels were made in an 18-lb., 35-kVA., high-frequency furnace, with conditions such as time of melting, temperature, time and method of addition of the alloys, carefully controlled. By this means it was hoped to eliminate as far as possible any manufacturing variables, so that results would indicate only the effect of the various elements themselves.

For these steels, Armco-iron scrap was used containing only a small quantity of residual elements. Thus, apart from the elements listed, all the steels may be taken to have the following analysis:

S, %	P, %	Ni, %	Cr, %	Mo, %	Cu, %	Sn, %	N, %
0.021	0.009	0.04	Trace	Trace	Trace	0.007	0.006

All the production steels were made by the basic open-hearth process in furnaces of approximately 60 tons capacity.

PREPARATION OF TEST-PIECES

All the 18-lb. high-frequency ingots were forged to 1-in. sq. section and ample discard was taken from top and bottom of the ingot to ensure that the remaining steel was uniform in composition.

From the two casts of open-hearth steel with varying aluminium additions, lengths of 3-in. dia. bars were obtained from the middle of each ingot and re-rolled to 1-in. in dia. From the production

steels a small length of 3-in. dia. bar was taken from the middle of the middle ingot and forged to 1-in. sq. section.

GRAIN-SIZE

McQuaid-Ehn grain-size tests were carried out on all the steels as shown in Tables II, III, and IV, and, as to be expected, with increasing aluminium addition the grain-size became finer, usually with a more or less sudden jump between 1 and $1\frac{1}{2}$ lb. of aluminium per ton.

However, since it is the degree of coarseness or fineness of the final structure of the steel, and also

normalizing temperature was that by this treatment a high degree of uniformity of structure was obtained in all the high-frequency-furnace steels (as shown in Table II). The grain-size was determined as follows: Since all the steels were of low carbon content, the pearlite could be ignored and the "ferrite grain-size" measured in the same way as the McQuaid-Ehn grain-size. A careful examination of numerous microsections did not indicate any significant difference in the final structure of coarse- or fine-grained steels after normalizing at 920° C. (Typical photomicrographs are shown in Fig. 2.) At a higher



FIG. 2(a)— $\times 500$

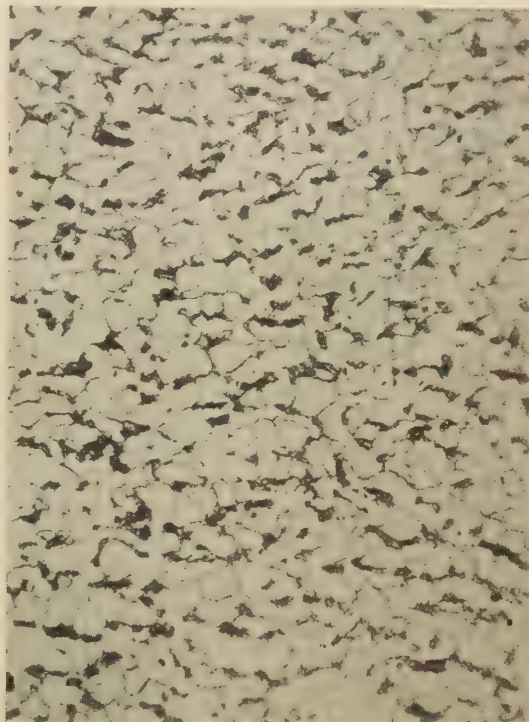


FIG. 2(b)— $\times 100$

FIG. 2—Typical microstructures of a high-frequency cast

the rate of cooling from the normalizing temperature which influences the creep strength, rather than the McQuaid-Ehn grain-size, it was considered that some control by heat-treatment of this structure was necessary.

HEAT-TREATMENT

The test bars were normalized by heating to a temperature of 920° C. and after 1 hr. at temperature allowing the bars to cool freely in air. It is preferable in practice when normalizing such steels to use a higher temperature, *e.g.*, 950° C., which tends to coarsen the structure and thus improve the creep. The reason for the lower

temperature the steels of lower aluminium began to coarsen. That the method of manufacture, *i.e.*, high-frequency furnace, helped in obtaining this uniformity was shown by the fact that in the case of the open-hearth steels, the same degree of uniformity was not obtained.

Thus, by normalizing all the steels to obtain a uniformly fine structure, it was considered that the effect of grain-size variation was eliminated and that the results obtained would more clearly reflect the effect of the alloying elements themselves, particularly their effect on abnormal creep, which is most pronounced when the structure is fine.

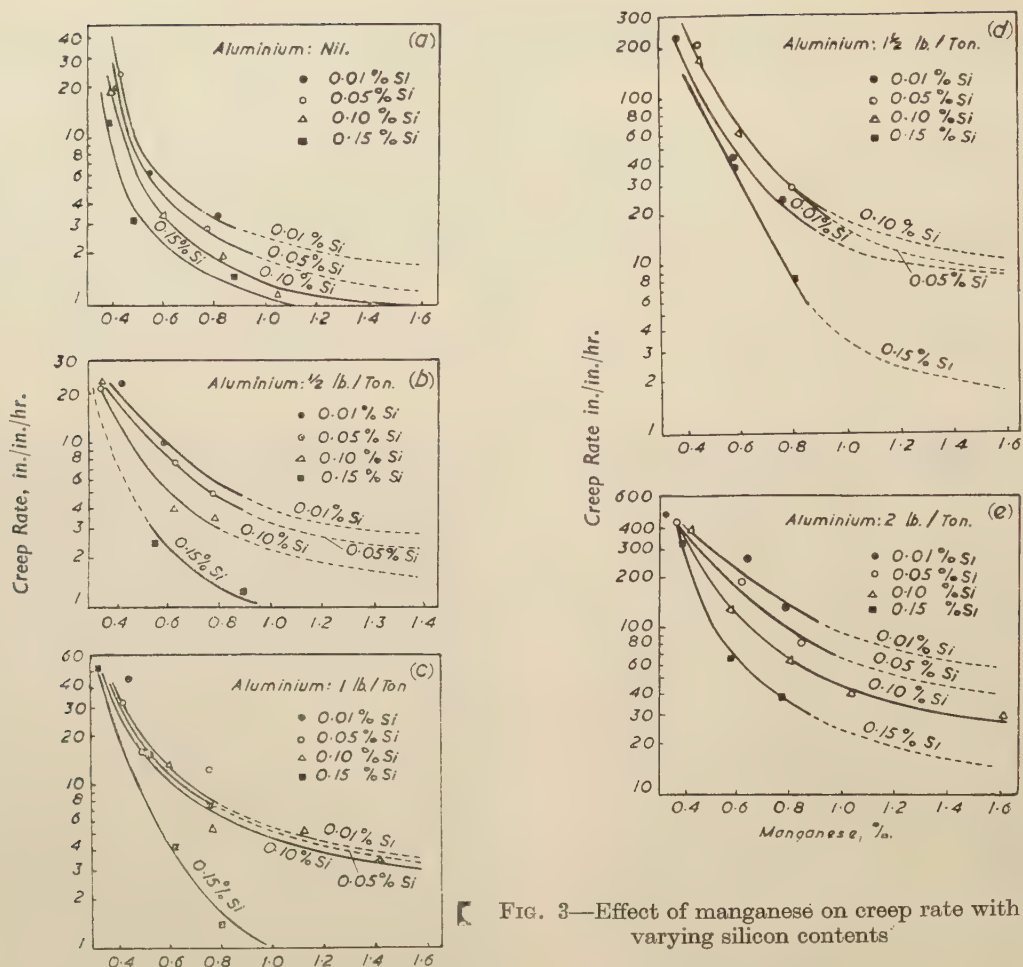


FIG. 3—Effect of manganese on creep rate with varying silicon contents

TESTING PROCEDURE

As already stated, the creep tests carried out were made at a temperature of 450° C. and a stress of 8 tons/sq. in., the duration of each test being 5 days in order to allow a fresh batch to be tested each week. The rate of loading in every case was 1000 lb./sq. in./min.

The method of presenting the data has been to include the creep rate at a period of 1, 2, 3, 4, and 5 days, the initial plastic strain, and also the total plastic strain at 1, 2, 3, 4, and 5 days.

RESULTS

The chemical analysis, aluminium additions, grain-size, and creep data obtained are recorded in Table II. It will be noted that, while the carbon content may be considered constant, and the steels may be arranged in groups of silicon contents of 0.01, 0.05, 0.10, and 0.15% respectively, there is some scatter in the manganese percentage. Graphs were therefore first prepared to show the effect of manganese on the

creep rate in steels of different silicon content and with different aluminium additions (Fig. 3). The creep rate at the end of five days has been used in these and subsequent graphs and since the creep rates varied over a wide range these are plotted on a log scale. Considering the number of imponderable variables which might influence the results, the smooth curves drawn through the plotted points may be taken as representing to a very close approximation the effect of manganese, silicon, and aluminium. The remaining curves to be discussed have been derived from the curves shown in Fig. 3.

Effect of Manganese

In every series the creep rate is reduced as the manganese is increased and its effect is most pronounced in the lower ranges. The tensile strength is also increased with manganese, but in this case the effect is more marked in the higher ranges of manganese. Figures 4 and 5 show the effect of increasing aluminium with increased

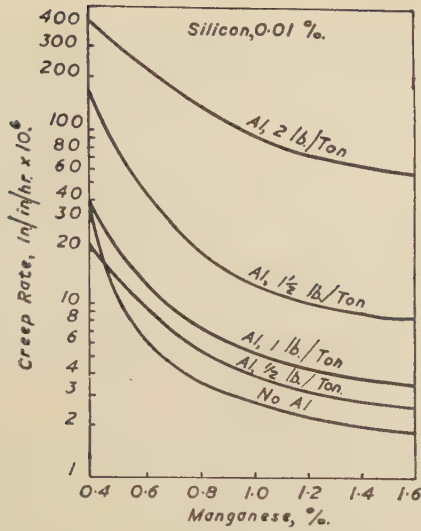


FIG. 4

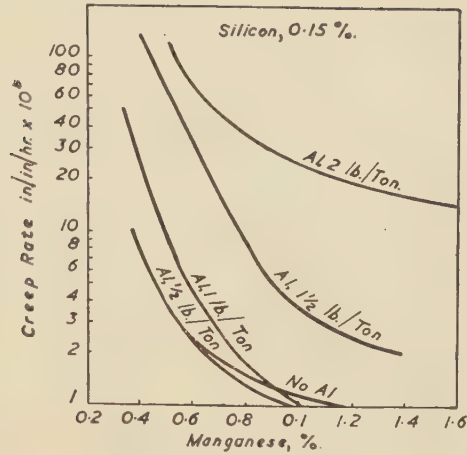


FIG. 5

FIGS. 4 and 5—Effect of manganese with varying amounts of silicon and aluminium

manganese on steels containing 0.01% and 0.15% of silicon respectively. It will be noted that in the higher ranges of manganese, particularly with 0.15% of silicon, low creep rates are obtained with aluminium contents less than 2 lb./ton, although, as can be seen from Table II, these steels are fine-grained.

Effect of Silicon (Figs. 6 and 7)

Considering the small range of silicon, its effect is quite considerable, particularly in the series with high manganese contents. Two points of particular interest are shown in Fig. 7. With 1½ lb. of aluminium the creep rate increases with increasing silicon up to 0.08% and thereafter decreases rapidly. All these steels with 0.8% of manganese and 1½ lb. of aluminium are fine-grained. Also, with 1 lb. of aluminium, the high-

manganese steel containing 0.16% of silicon, although fine-grained, has a lower creep rate than the same steel with 0.01% of silicon, although the latter is coarse-grained. These results illustrate quite clearly that a fine grain-size in itself is not responsible for abnormal creep rates.

Effect of Aluminium (Figs. 8 and 9)

These curves show that with the exception of the 0.4% manganese steel and those steels containing 0.15% of silicon, the effect of aluminium is to increase the creep rate. With 0.4% of manganese the first small addition of aluminium appears to be beneficial, although these results may be due to experimental error. In the high-silicon steels, however, this beneficial effect seems to be reasonably well established. The creep rate increases rapidly as the aluminium additions

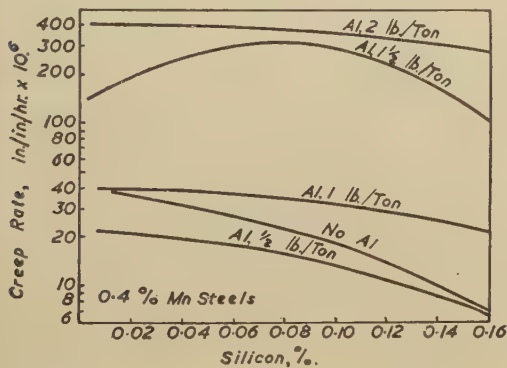


FIG. 6

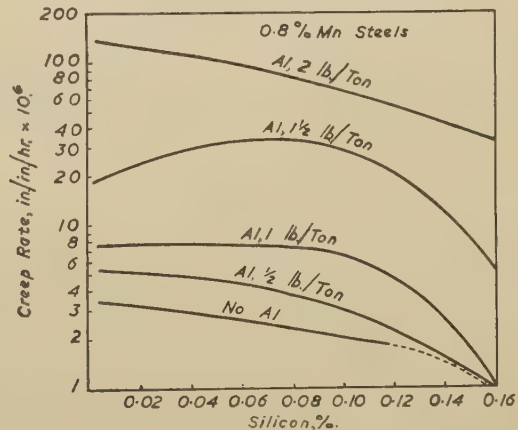


FIG. 7

FIGS. 6 and 7—Effect of silicon with varying amounts of manganese and aluminium

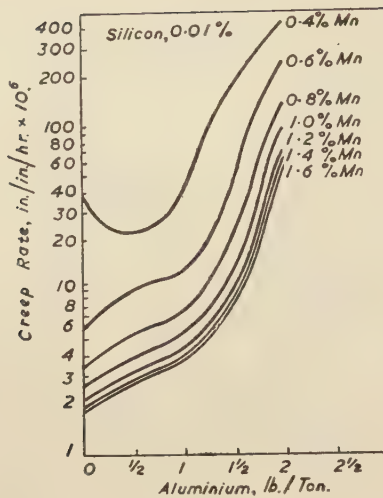


FIG. 8

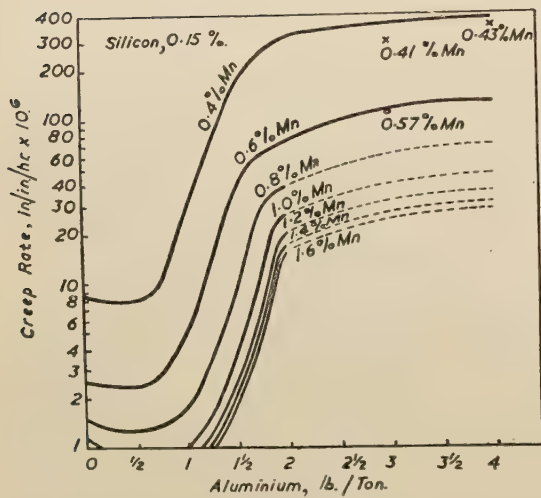


FIG. 9

Figs. 8 and 9—Effect of aluminium with varying amounts of silicon and manganese

are increased from 1 to 2 lb., but again it will be noted that the high-manganese, high-silicon steels still show low creep rates with aluminium additions of less than 2 lb.

Effect of Residual Molybdenum

Samples of 3-in. dia. rolled bar were obtained from 30 casts of basic open-hearth steel to each of which 2 lb. of aluminium per ton had been added to the ladle. The samples were re-rolled to 1-in. squares and normalized at 920° C. Analysis, grain-size, and creep data are shown in Table III. The McQuaid-Ehn grain-size results divide the steels into three groups, coarse-grained (1-3), mixed-grained (1-3, 6-8), and fine-grained. The ferrite grain-size of these steels is not so uniform

TABLE III—Basic Open-Hearth Casts

Steel No.	Analysis										Grain-Size		Creep Rate, in./in./hr. $\times 10^6$					Total Plastic Strain, %					Initial Plastic Strain, %
	C, %	Si, %	S, %	P, %	Mn, %	Ni, %	Cr, %	Mo, %	McQuaid-Ehn	Ferritic	1 Day	2 Days	3 Days	4 Days	5 Days	1 Day	2 Days	3 Days	4 Days	5 Days			
C 1	0.09	0.05	0.029	0.011	0.46	0.11	0.04	0.01	6-8	7-8	64.2	306.0	420.0	370.0	324.0	0.543	3.66	5.03	6.12	7.06	7.88		
C 2	0.095	0.05	0.030	0.021	0.51	0.16	0.03	0.03	6-8	6-8	484.0	210.0	259.0	233.0	212.0	0.449	2.70	3.62	4.28	4.86	5.98		
C 3	0.11	0.08	0.026	0.010	0.43	0.10	0.04	0.03	6-8	7-8	294.0	305.0	196.0	180.0	166.0	0.394	1.94	2.49	2.97	3.43	3.83		
C 4	0.10	0.03	0.022	0.012	0.46	0.16	0.05	0.035	6-8	6-8	308.0	252.0	206.0	184.0	170.0	0.398	2.02	2.70	3.24	3.70	4.12		
C 5	0.105	0.05	0.033	0.013	0.52	0.16	0.04	0.045	6-8	6-8	196.0	154.0	126.0	110.0	102.0	0.288	1.24	1.65	1.99	2.27	2.52		
C 6	0.105	0.05	0.032	0.021	0.49	0.15	0.05	0.04	6-8	6-8	70.1	45.8	41.9	37.2	35.0	0.285	0.642	0.773	0.877	0.963	1.05		
C 7	0.10	0.04	0.034	0.013	0.53	0.11	0.06	0.045	7-8	7-8	332.0	238.0	196.0	180.0	160.0	0.207	1.76	2.42	2.93	3.38	3.78		
C 8	0.11	0.05	0.031	0.013	0.50	0.14	0.05	0.05	6-8	7-8	166.0	144.0	128.0	108.0	94.0	0.319	1.26	1.62	1.95	2.22	2.46		
C 9	0.10	0.03	0.039	0.013	0.44	0.20	0.07	0.06	6-8	6-8	154.0	136.0	122.0	112.0	100.0	0.224	1.46	1.95	2.32	2.62	2.88		
C 10	0.09	0.03	0.027	0.024	0.47	0.16	0.05	0.11	7-8	6-8	84.2	61.2	52.0	49.1	48.0	0.192	0.577	0.748	0.885	1.04	1.12		
C 11	0.09	0.04	0.030	0.010	0.47	0.16	0.07	0.05	7-8	6-8	78.8	41.4	32.0	29.6	28.0	0.263	0.726	0.866	0.983	0.951	1.02		
C 12	0.09	0.04	0.030	0.010	0.44	0.15	0.07	0.13	7-8	7	74.1	55.2	41.6	34.0	28.8	0.258	0.780	0.919	1.03	1.09	1.16		
C 13	0.12	0.05	0.024	0.012	0.48	0.15	0.04	0.02	1-3, 6-8	4-6	78.0	52.0	40.1	29.8	23.0	0.228	0.635	0.732	0.792	0.838	0.872		
C 14	0.115	0.05	0.024	0.015	0.50	0.13	0.04	0.04	1-3, 6-8	4-8	58.0	32.4	22.0	16.4	13.1	0.184	0.518	0.600	0.654	0.694	0.722		
C 15	0.105	0.04	0.029	0.013	0.47	0.14	0.05	0.055	1-3, 6-8	4-5	47.2	28.2	18.6	14.6	10.2	0.224	0.446	0.495	0.532	0.562	0.588		
C 16	0.105	0.05	0.034	0.010	0.48	0.21	0.05	0.07	1-3, 6-8	4-6	24.6	18.2	14.0	11.6	9.4	0.202	0.429	0.488	0.523	0.550	0.573		
C 17	0.10	0.04	0.028	0.011	0.48	0.22	0.05	0.07	1-2, 6-8	4-5	31.6	17.0	13.2	10.6	8.1	0.221	0.594	0.688	0.737	0.775	0.800		
C 18	0.11	0.03	0.037	0.010	0.43	0.17	0.05	0.085	1-3, 6-8	4-6	52.3	29.5	20.9	12.4	8.1	0.247	0.711	0.798	0.867	0.942	1.01		
C 19	0.08	0.05	0.036	0.011	0.52	0.10	0.02	0.01	1-3	3-4	45.9	32.2	23.8	18.8	14.6	0.310	0.726	0.828	0.896	0.948	0.988		
C 20	0.07	0.03	0.028	0.013	0.45	0.09	0.02	0.02	1-3	3-4	52.8	33.2	24.4	18.8	14.6	0.216	0.756	0.858	0.926	0.978	1.01		
C 21	0.11	0.04	0.023	0.011	0.49	0.11	0.03	0.035	1-3	4-5	44.6	27.8	19.4	14.8	11.4	0.194	0.604	0.700	0.748	0.786	0.806		
C 22	0.105	0.06	0.026	0.010	0.41	0.13	0.02	0.04	1-3	3-5	51.2	28.8	20.4	12.0	7.8	0.235	0.735	0.835	0.886	0.948	0.988		
C 23	0.115	0.04	0.030	0.012	0.52	0.17	0.03	0.055	1-3	4-6	36.3	23.6	16.4	11.8	7.4	0.167	0.430	0.504	0.551	0.582	0.608		
C 24	0.10	0.04	0.030	0.012	0.52	0.16	0.03	0.055	2-4	4-6	27.0	16.4	11.8	7.6	5.8	0.153	0.366	0.442	0.492	0.531	0.561		
C 25	0.08	0.04	0.025	0.012	0.51	0.16	0.07	0.06	1-4	3-5	26.8	14.6	9.6	7.6	4.8	0.126	0.274	0.340	0.381	0.427	0.477		
C 26	0.14	0.04	0.022	0.015	0.54	0.18	0.03	0.075	1-3	3-4	32.0	17.0	11.2	9.6	4.8	0.246	0.412	0.514	0.544	0.581	0.604		
C 27	0.08	0.04	0.025	0.015	0.51	0.16	0.03	0.075	1-3	3-4	30.6	17.0	11.2	9.6	4.8	0.171	0.352	0.452	0.477	0.514	0.544		
C 28	0.115	0.05	0.024	0.012	0.50	0.23	0.05	0.075	1-4	4-6	28.4	12.8	10.2	8.0	5.2	0.161	0.352	0.452	0.477	0.514	0.544		
C 29	0.11	0.05	0.036	0.014	0.46	0.21	0.06	0.075	1-3	3-4	17.4	11.6	7.2	6.4	5.8	0.134	0.243	0.276	0.296	0.312	0.326		
C 30	0.10	0.03	0.029	0.013	0.45	0.13	0.06	0.08	1-3	4-6	17.4	11.6	7.2	6.4	5.8	0.134	0.243	0.276	0.296	0.312	0.326		

Steel No.	Aluminium, lb./ton	Analysis										Grain-Size		Creep Rate, in./in./hr. $\times 10^6$						Creep Strain, %				
		C, %	Si, %	S, %	P, %	Mn, %	Ni, %	Cr, %	Mo, %	McQuaid-Ehn	Ferritic			1 Day	2 Days	3 Days	4 Days	5 Days	Initial	1 Day	2 Days	3 Days	4 Days	5 Days
A1	$\frac{1}{2}$	0.10	0.07	0.026	0.010	0.41	0.10	0.04	0.03	2.4	3.5			16.1	8.0	6.4	4.6	3.8	0.087	0.241	0.275	0.295	0.308	0.320
A2	$1\frac{1}{2}$	0.12	0.08	0.026	0.010	0.50	0.09	0.04	0.03	3, 5-7	4.6			18.0	11.4	7.1	4.8	4.0	0.112	0.272	0.328	0.362	0.377	0.398
A3	2	0.12	0.08	0.026	0.010	0.43	0.10	0.04	0.03	6.8	6.8			294.0	210.0	196.0	180.0	166.0	0.394	1.94	2.49	2.97	3.43	3.83
A4	$2\frac{1}{2}$	0.105	0.08	0.026	0.010	0.42	0.10	0.04	0.03	7.9	6.8			310.0	236.0	272.0	256.0	250.0	0.460	2.34	3.04	3.71	4.33	4.93
A5	3	0.11	0.08	0.026	0.010	0.42	0.10	0.04	0.03	7.9	6.8			320.0	295.0	281.0	262.0	251.0	0.482	2.72	3.45	4.23	4.88	5.49
A6	$\frac{1}{2}$	0.11	0.08	0.026	0.010	0.42	0.10	0.04	0.03	1.4	3.5			17.4	9.1	8.2	4.7	4.0	0.092	0.252	0.288	0.301	0.316	0.331
B1	1	0.10	0.04	0.029	0.010	0.46	0.15	0.05	0.11	3.4	4.6			12.4	8.2	6.0	4.6	4.0	0.104	0.180	0.201	0.218	0.230	0.241
B2	$1\frac{1}{2}$	0.085	0.04	0.029	0.011	0.46	0.15	0.05	0.11	4, 5-7	4.6			16.4	11.2	8.0	7.0	6.2	0.121	0.214	0.242	0.265	0.282	0.299
B3	2	0.095	0.04	0.030	0.010	0.47	0.16	0.05	0.11	7.8	6.8			38.8	26.4	22.6	20.6	19.6	0.193	0.407	0.480	0.537	0.588	0.641
B4	$2\frac{1}{2}$	0.10	0.04	0.031	0.010	0.47	0.16	0.06	0.11	7.9	6.8			78.0	41.4	31.4	27.4	26.2	0.235	0.671	0.800	0.883	0.952	1.02
B5	3	0.10	0.04	0.030	0.011	0.46	0.16	0.06	0.11	7.9	6.8			76.2	41.6	35.2	33.2	31.2	0.256	0.584	0.698	0.790	0.868	0.947
B6	1	0.085	0.04	0.031	0.012	0.45	0.16	0.06	0.11	3.4	4.6			13.1	8.5	6.3	4.8	4.3	0.111	0.201	0.224	0.237	0.255	0.268

as that of the high-frequency casts, the steel of coarse McQuaid-Ehn grain-size tending to give a coarser ferrite grain-size. Apart from the molybdenum and nickel contents, the steels were of reasonably uniform analysis and therefore, since the effect of nickel appears to be negligible, curves were drawn showing the effect of residual molybdenum (Fig. 10). As might be expected, the fine-grained steels have a higher creep rate

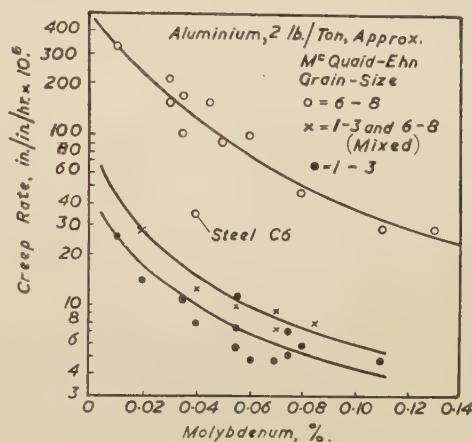


FIG. 10—Effect of molybdenum on creep strength of open-hearth tube steel

than the coarse-grained steels, but in each group the effect of molybdenum is to decrease considerably the creep rate. In particular it will be noted that the fine-grained steels with more than 0.10% of molybdenum have as low a creep rate as the coarse-grained steels with less than 0.01% of molybdenum. It will be noted that steel C6 shows a lower creep rate than the other steels in its group.

The effect of 0.1% of molybdenum was further investigated with two basic open-hearth casts of mild steel to which different amounts of aluminium were added to individual ingots. The ingots were rolled to 3-in. dia. bars, and test lengths cut from the middle of each ingot were re-rolled to 1 in. in dia. In cast A 8 oz. of aluminium per ton and in cast B 1 lb. of aluminium per ton were added to the ladle and the remainder to the moulds. Aluminium additions, analysis, grain-size, and creep data are shown in Table IV, and the creep rate is plotted against the aluminium content in Fig. 11. As with the high-frequency casts an increase in creep rate is found with aluminium additions of $1\frac{1}{2}$ –2 lb., but with the low-molybdenum steel the transition is abrupt. With the higher-molybdenum steels the transition is more gradual and the increase in creep rate considerably less. In both series the change in creep rate coincides with the transition from

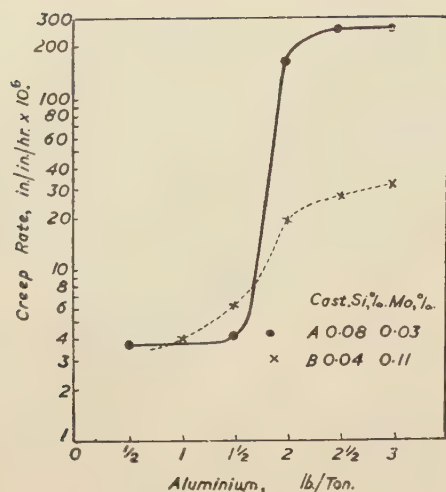


FIG. 11—Effect of aluminium on creep strength

coarse-grained to fine-grained. It will have been noted that all the steels examined which have shown high creep rates are fine-grained, but not all fine-grained steels exhibit high creep rates. The transition from normal to abnormal creep rates is abrupt, except with the steels containing high residual molybdenum. The transition from coarse grain-size to fine grain-size is more gradual, mixed grain-sizes being frequently encountered. The creep characteristics of mixed-grained steels more closely approximate to those of coarse-grained steels. It thus appears that more aluminium than is sufficient to make the steel fine-grained is necessary to produce abnormal creep. In low-manganese-silicon steels containing low residual molybdenum (that is, normal production open-hearth mild steels) the two effects follow so closely upon one another that practically all fine-grained steels of this type give abnormally high creep rates; steel C6 (Fig. 10) is a borderline example. On the other hand the gap between obtaining a fine grain-size and obtaining low creep resistance is widened by manganese, silicon, or residual molybdenum, so that such steels may be fine-grained without showing abnormal creep.

Sufficient material being available, creep tests of 1000 hours' duration were carried out on some of the residual-molybdenum steels listed in Table IV; the results are plotted in Fig. 12, and the creep rates at the end of the tests are shown in Table V; the very low creep-rate values, however, can be considered only as approximate.

The above creep tests clearly establish that a fine-grained mild steel gives an inferior creep strength even at a temperature of 600° F. At 500° F. there appears to be no difference between the coarse- and fine-grained steels, but above 600° F. the fine-grained steel becomes progressively worse than the coarse-grained as the temperature increases. The presence of 0.11% of molybdenum is sufficient to cause the fine-grained steels to behave more or less normally in this respect. These results are in agreement with those obtained in the short-time creep tests. At temperatures of approximately 800° F. or above, the effect of 0.1% of molybdenum is not quite sufficient to counteract completely the effect of aluminium in promoting abnormal creep, but there seems no reason to doubt that a slightly higher percentage of molybdenum would be sufficient for the purpose.

SUMMARY AND CONCLUSIONS

Short-time creep tests have been carried out on low-carbon steels containing 0.4–1.5% of manganese, 0.01–0.15% of silicon, and 0–0.11% of molybdenum, and with varying amounts of aluminium up to 3 lb./ton. To ensure as far as possible the elimination of effects due to ferrite grain-size, all the steels were normalized at 920° C. and the high-frequency casts particularly gave a uniform ferrite grain-size. The creep test employed was 5 days at 450° C. with a stress of 8 tons/sq. in., and the creep rate at the end of 5 days was utilized in graphing the results. As shown by Tapsell, this test clearly indicates whether low-carbon, low-silicon steel has, or has not, abnormal creep properties.

It has been shown that manganese, silicon, and

TABLE V—Creep Rates of Various Steels at the End of 1000-hr. Tests

Grain-Size		Steel	Molybdenum, %	Aluminium, lb./ton	Creep Rate, in./in./hr. $\times 10^6$			
McQuaid-Ehn	Ferritic				500° F., 6 tons/sq. in.	600° F., 6 tons/sq. in.	700° F., 5 tons/sq. in.	800° F., 4 tons/sq. in.
2-4	3-6	A1	0.03	$\frac{1}{2}$	Neg.	...	0.1	0.1
6-8	6-8	A3	0.03	$1\frac{1}{2}$	Neg.	1.15	1.85	5.5
3-4	4-6	B1	0.11	1	Neg.	...	0.05	0.2
7-9	6-8	B5	0.11	3	Neg.	0.2	0.2	0.4

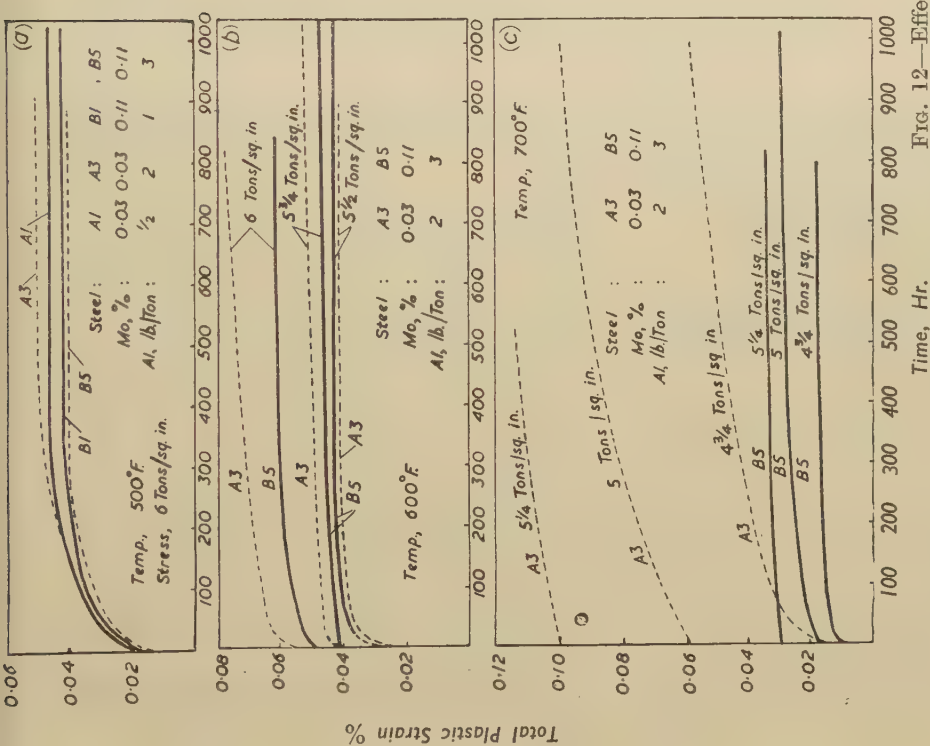


FIG. 12—Effect of molybdenum on creep strength

molybdenum within the limits examined reduce the creep rate and that the abnormal creep resulting from aluminium additions is reduced considerably by these elements. All the steels with high creep rates are fine-grained, but the steels in the higher ranges of manganese, silicon, and molybdenum examined, though fine-grained, do not exhibit abnormal creep unless an excess of aluminium is present. In this connection it is important to understand clearly what is meant by abnormal creep. This has been defined as a deterioration in creep characteristics due to deoxidation practice, involving differences in the amounts of aluminium and silicon used. However, it should be borne in mind that this deterioration is only appreciable in normal low-carbon steels when the aluminium addition has been sufficient to give the steel a fine grain-size, as measured by the McQuaid-Ehn test. Thus, with proper control, aluminium may be used as a deoxidizer provided that the steel remains coarse-grained. It has been shown³ that aluminium tends to promote graphitization, but the effect is appreciable only when the aluminium addition is such as results in a fine grain-size.

On the other hand, the higher residual-molybdenum steel with 2 lb. of aluminium per

ton and with a fine grain-size does not show the same deterioration in creep. However, this steel must also be considered to exhibit abnormal creep, for, if coarsened by normalizing from 1100° C. the creep properties are enhanced in the same way as are those of fine-grained steels with low-silicon, manganese, and molybdenum.

Tests of 1000 hours' duration up to 800° F. on the molybdenum steels place them in the same order of merit as does the short-time creep test. It is recognized, however, that even this test is not of sufficient duration to test adequately the effect of time and temperature on the resistance to creep.

As already stated, a serious limitation of the short-time test at an arbitrary temperature is that it does not take into consideration the effect of higher temperatures and/or longer times on the structure and, consequently, on the creep-resisting properties of the steel. For example, it has been shown that silicon improves the creep resistance under the conditions of the test. It is well known, however, that silicon tends to promote spheroidization and graphitization and therefore at higher temperatures and with longer times of test it may well prove harmful. On the other hand, Jenkins and others⁴ have shown that the higher the manganese-silicon ratio the less tendency there is for spheroidization. Manganese would,

therefore, be expected to prevent deterioration in creep resistance at higher temperatures and with longer times of testing.

In conclusion it may be said that manganese, silicon, and molybdenum, within the composition limits examined and under the test conditions described, while modifying the effect of aluminium in producing abnormal creep, do not eliminate it. The mechanism of this effect, which appears to be peculiar to aluminium, remains to be elucidated and further work to this end is in progress.

ACKNOWLEDGMENTS

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SPECIAL SUMMER MEETING IN ZURICH

The June Journal

As announced in the News Section of the February issue of the *Journal*, a special Summer Meeting of the Institute is to be held in Switzerland, in July, 1947. For the convenience of Members the whole of the papers to be presented at the meeting are being published in the June issue of the *Journal*. The principal contents of this special issue will be as follows:

The second Hatfield Memorial Lecture:

"*Steels for use at Elevated Temperatures*" by Dr. C. Sykes, F.R.S.

"*Hydrogen and Transformation Characteristics in Steel*" by Professor J. H. Andrew, D.Sc., H. Lee, Ph.D., H. K. Lloyd, B.Sc., and N. Stephenson, B.Met.

"*Hydrogen in Steel Manufacture*" by Dr. C. Sykes, F.R.S., H. H. Burton, and C. C. Gegg.

"*The Production of Iron and Steel with*

Oxygen-enriched Blast" by Robert Durrer.

"*Electric Smelting*" by Robert Durrer.

"*The Scaling Behaviour of High-strength Heat-resisting Steels in Air and Combustion Gases*" by W. Stauffer and H. Kleiber.

"*Possibilities for the extended use of Oxygen in the British Steel Industry*" by M. W. Thring.

"*Considerations regarding the carrying out and interpreting of Creep Tests*" by W. Siegfried.

There will also be papers on New Processes for the Electric Welding of Rails, submitted by S.A. des Ateliers de Sécheron; Metallurgical Aspects of Gas Turbines, submitted by A. G. Brown, Boveri et Cie, and a Review of the Swiss Metal and Machine Industry, submitted by the Verein Schweizerischer Maschinen-Industrieller.

The Iron and Steelworks Engineering section of the *Journal* will be devoted to a description of the Electric Furnace at the works of Gesellschaft der Ludwig von Roll'schen Eisenwerke, A.G., at Choindez.

The News Section will contain brief descriptions of works and installations to be visited in Switzerland, and will give biographical notes of the authors of papers contributed to the Meeting.

BLOWING-OUT A BLAST-FURNACE*

By R. Fowler†

SYNOPSIS

General considerations in blowing-out a blast-furnace are discussed and blowing-out procedures are reviewed. The method adopted at the Ebbw Vale plant of Messrs. Richard Thomas and Baldwins, Ltd., is outlined, and an account is given of a particular blowing-out operation at these works. The blowing out of No. 3 blast-furnace at the works of The Park Gate Iron and Steel Co., Ltd., Rotherham, is described by Mr. J. W. Houghton in an Appendix.

INTRODUCTION

IT has been stated that a blast-furnace is blown-out by not charging any more material, tapping out all the molten iron and slag, and then taking off the blast.

For the performance of such a significant operation, requiring very careful thought and pre-planning, this statement is so simple and direct that it does not even suggest that there may be any complex problems or risks to be guarded against whilst carrying out the operation.

In the literature frequent reference is made to the blowing-out of a furnace and the dangers which are liable to occur during the progress of that operation, but the question is treated only in a very general and inadequate manner, which is of very little assistance to those who wish to improve their knowledge of the subject.

It is hoped that the following observations and the description of an actual blow-out may result in the initiation of a frank discussion on the various methods of blowing-out, and in the development of a more efficient and safe procedure in one of the most important and anxious periods of blast-furnace operation.

GENERAL CONSIDERATIONS IN BLOWING-OUT

Unless special circumstances demand that the furnace should remain in operation after its economic and useful life is over, the continuation of any furnace campaign on a worn-out lining or unsafe hearth structure is unjustified and is very often the source of enormous loss to any productive establishment, a decisive factor which seems to be frequently overlooked in an elaborate effort to achieve a large production on a refractory lining.

It is false economy to set a standard tonnage for any furnace campaign. The economics of practice and the cost of the product should determine the end of the furnace life, and any self-glorification derived from achieving a large tonnage on a lining is poor compensation for losing money as well as the record of the furnace organization in maintaining a low fuel consumption. The immensity of the units dealt with, the large and definite responsibilities which are involved, and the long periods of time which may pass before new ideas are approved or condemned in practice, compel caution and conservatism to be observed. The necessity for a continuous production of large quantities of molten iron and slag, with the consequent generation of enormous volumes of explosive gases, and the task of confining these molten and gaseous streams within their proper channels result in dangers and hazards around the blast-furnace. Air and gas, flames and steam, molten iron and slag, and flowing water must all be kept side by side and in their correct places, otherwise serious consequences are bound to occur. Over-eagerness, inexperience, carelessness, and negligence, even in small details, in blast-furnace operations may bring disastrous results to plant and personnel.

Whatever the cause for blowing-out a furnace, it is necessary to aim at removing every possible quantity of molten iron at the last cast, in order to avoid any large salamander remaining in the hearth and the consequent delay and high cost through having to drill and blast this salamander into pieces small enough to handle. Careful planning of the whole operation should be thoroughly

* Received 12th August, 1946.

† Messrs. Richard Thomas and Baldwins, Ltd., Ebbw Vale.

discussed by all those who are directly responsible for any part of it, no matter how small or large their contribution may be, to bring about a successful issue. Nothing should be left to chance. All testing instruments and accessories required during the operation should be thoroughly checked before the operation is commenced, as the necessity for a safe blowing-out makes cost a secondary consideration.

When the furnace is in good condition and is blown out because of a reduction in the demand for iron, great care should be taken to protect and preserve the lining from damage and to avoid a too-rapid cooling of the furnace, especially if water is used during the blowing-out period and after the furnace is finally taken off blast.

Where the lining in the upper section of the furnace is in such a worn-out condition that the shell is exposed to the heat of the gases and materials inside the furnace, strict precautions must be exercised to keep the shell plates cool so that they are not distorted by heat, as this may result in the derangement of the furnace top.

The stock column must be prevented from becoming too low in the furnace before the volume and pressure of the blast are reduced, to ensure that free hot air is not blown directly through the light stock column, which would allow an excess of oxygen to mix freely with the carbon monoxide and hydrogen gases which fill the void above the stock column, thereby creating a highly explosive mixture.

Steps must be taken to prevent the stock from hanging or wedging during blowing-down, especially when water is used during the operation. This is particularly important, as the stock may become saturated with water—some parts more than others—while the furnace is hanging. When the column slips or is made to slip by checking the furnace, this highly saturated material may be precipitated lower down into the hotter section of the furnace and thus come into contact with incandescent coke and hotter wall surfaces, most probably with the generation of steam and water gas, which may produce disastrous results.

When blowing-out with water, to keep the top temperature to a predetermined higher limit water sprays are often used on the bell to keep it cool. Precautions must be taken so that water cannot possibly collect in quantity on the large bell and be accidentally precipitated into the furnace, thereby causing a violent generation of steam and hydrogen.

Total or partial failure of the water supply to the sprays in the furnace must be guarded against so that the top temperature is not allowed to rise and bring the gases within explosive limits.

Under such circumstances explosions may be started at some point by an external source of heat or surface-contact action, such as a fireclay surface or oxides of metal.

At this point it is as well to note that, in view of a possible water-supply failure, it is advisable to arrange a steam connection into the water-supply line so that, if the water fails, manipulation of two valves will close the water main and release a supply of steam to maintain a blanket in the top of the furnace through the spray-pipes in the test-rod holes. This would have a damping effect upon the gas and help to keep the top cool.

The last and probably the most hazardous stage of the blowing-out period is of vital importance, as it may determine the success or failure of the whole operation.

Much will depend on whether there are other units operating at the same time. Great care must be taken in purging-out and opening-up the dust-catcher when more than one furnace is in operation, and, in conjunction with this, the purging-out and opening-up of the gas mains when only one furnace is in operation and the plant is to be totally closed down.

The operating and opening of the furnace bleeders, dustcatcher valves, and gas-mains doors must be carefully manipulated, so that the furnace bleeders do not act as a chimney and pull air into the gas system where it can mix with gas and form an explosive mixture. The action of the furnace bleeders as a chimney in pulling this explosive mixture through the furnace top—where the brickwork may be at a very high temperature owing to the blowing-out conditions—makes ignition of the explosive mixture of gas and air, with consequent serious damage, highly probable.

BLOWING-OUT PROCEDURES

A review of the many methods adopted for blowing-out a furnace revealed that variations in practice are probably as great in number as are blast-furnace managers.

This diversity of methods is most interesting, and in 25 methods reviewed 20 are clearly dissimilar in practical application but similar in their final achievement. In 19 cases water sprays are placed in the test-rod holes to assist in keeping the top temperatures down to a predetermined figure. These top temperatures are quoted as being from 316° to 537° C. (600° to 1000° F.), a variation of some 205° C. (400° F.). In twelve cases water sprays are also fitted and used on the large bells, the bells being propped open or having spacers fitted, giving a gap varying from $\frac{1}{4}$ to $\frac{3}{4}$ in. between the bell and the lip-ring. In six cases no water is used on the bells, and the bells are kept

closed. In seven cases no water is used at all during the blowing-out period, but either water or steam is used after the furnace is taken off blast, to quench or cool down the remaining burden left in the furnace. In the majority of cases, as the stock column descends in the furnace and offers less resistance to the blast pressure, the wind is progressively reduced. The height of the stockline level when the blast is finally taken off the furnace varies from the normal working level down to the bottom of the bosh. The method of final charging varies considerably. In some cases regular charges are lowered into the furnace at intervals varying from $\frac{1}{2}$ to 2 hr. A reduction in the ratio of coke to ore is also made in this practice.

In eight cases the furnace is kept full to the normal stockline level with normal working burden and, when the blast is finally taken off, the burden is quenched and cooled with water. In three cases the furnace is kept full of nut coke and no water is used during the blowing-out period. In most cases the final charges include varying quantities of combustible material. These range from coke blanks of 10–130 tons, coke dust and breeze obtained by emptying the coke bunkers, small coke with added converter slag, 20–30 tons or more of boiler ashes, according to circumstances, and up to 20 tons of damp flue dust.

In two cases, 9–100 tons of limestone are charged (3–40 cwt. per charge), being dumped into the furnace at intervals to regulate the top temperature. The calcination of this limestone generates CO_2 , dilutes the gas, and helps to keep the top temperature low.

Where nut coke is employed and the furnace is kept full to the normal stockline, no water is used during the actual blowing-out. The gases in this instance become richer as the blowing-out proceeds, up to the time when the furnace is taken off blast, but there is an advantage in the fact that if a shut-down becomes necessary the conditions are similar to those in normal operation and there is little cause for anxiety. When the blast is finally taken off and the quenching of the coke proceeds, there is a possibility of the coke hanging or arching over and not settling readily into the void created by the tapping-out of the last cast. The water used for quenching the coke may not be evenly distributed over the area of the bed and may run down in channels, and thus some parts of the coke may be thoroughly wetted whilst other parts remain hot. The coke may therefore contract suddenly, and wet coke may be precipitated into the voids and cause a rapid generation of steam, hydrogen, and, probably, water gas, which may cause disastrous results.

From the review of the various methods of blowing-out it was evident that the risk of violent slips of the burden and in particular the possibility of gas explosions, either during the blowing-out period or in the final operation of taking the furnace off the gas system, was realized by every operator.

BLOWING-OUT PROCEDURE AT EBBW VALE

It is not proposed to discuss all the methods of blowing-out a furnace, with their respective merits or demerits, in conjunction with the hazards which may be envisaged, but a method put into practice at Ebbw Vale which it is considered may be adopted with the least amount of risk to plant or personnel is described below.

The location of the plant, *i.e.*, whether it is in a rural or an urban area, or in the centre of a residential district, must have a bearing on the method to be adopted, and at Ebbw Vale, where the plant is situated in a residential area, precautions have to be taken to avoid opening-up furnace bleeders and bells and so allowing quantities of gas, fine ore, and coke dust to cause a nuisance under the Public Health Acts.

For many years the author has been very closely associated with the practice of blowing-down the furnace by the addition of water through sprays in the test-rod holes and also by sprays on the large bell, which was propped open.

When the gas became wild and unusable on account of the added water, the furnace was taken off the main gas system, the bleeders opened, and the gas blown to atmosphere. Eventually local reaction to dust nuisances made it imperative to adopt some other method not involving the opening of the bell or bleeders during the blowing-out procedure. As has been previously stated there is nothing new in blowing-out a furnace and leaving it full when the operation is completed, whether the normal charging burden is used or a blank of coke is charged and the ratio of ore to coke reduced. These methods are simple and reliable, as the furnace can be taken off blast at any time as if normal operation was in progress, the final procedure differing only in the cooling-down of the stock in the furnace, which of course has to be raked out and loaded up and taken away from the furnace site.

As previously remarked, a very high percentage of the final charges during blow-downs contain varying quantities of combustible matter in the nature of coke, nut coke, coke breeze and dust, and also boiler ashes. All these materials generate gas in proportion to the amount of combustible matter which they contain.

*Example of Blowing-Out Procedure at**Ebbw Vale—"A" Furnace*

It appeared desirable that no combustible material or water should be used during the blowing-down of the furnace concerned, so as to avoid the generation of any gas which produces the hazardous conditions visualized. It was therefore decided that no coke or other combustible material should be charged and that no water should be used from the time the blowing-out proper was commenced.

Blowing-out was scheduled to start at 6.0 A.M.; the last regular charge, with coke additions, was dumped into the furnace at 5.55 A.M., when the stockline level was recorded at 7 ft.

The first charge after 6.0 A.M. was composed entirely of raw Northamptonshire ore, this charging procedure being followed at regular intervals until the blast was finally taken off the furnace after the last cast, at 2.45 P.M. The actual time taken for the complete blowing-out was therefore $8\frac{3}{4}$ hr. The raw ore charged into the furnace was on a four-skip cycle, each skip weigh-

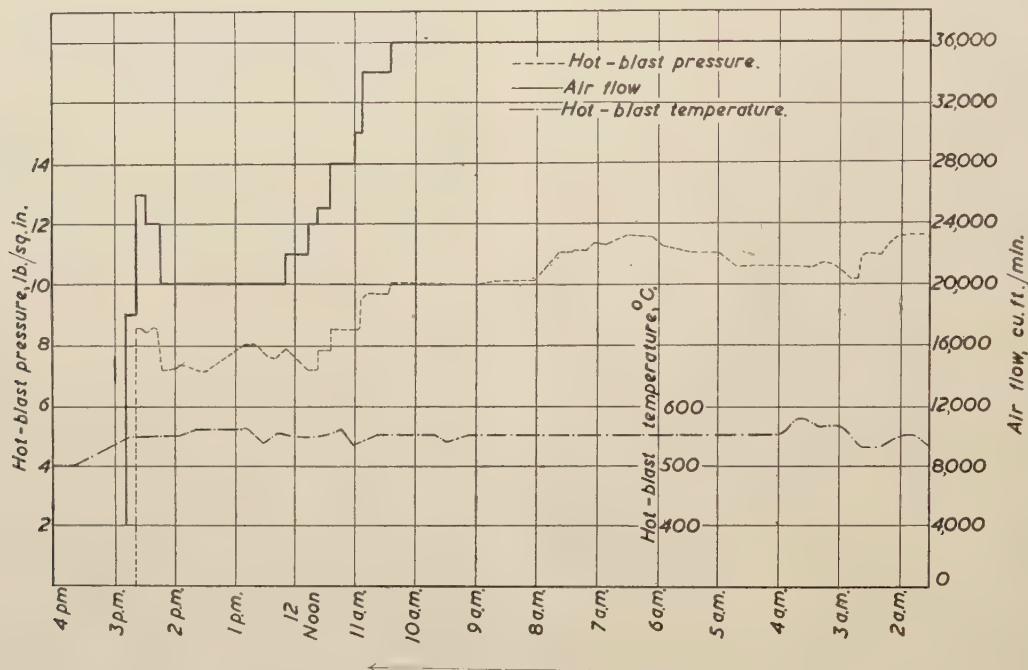


FIG. 1a—Records of the blow-out (see Fig. 1b)

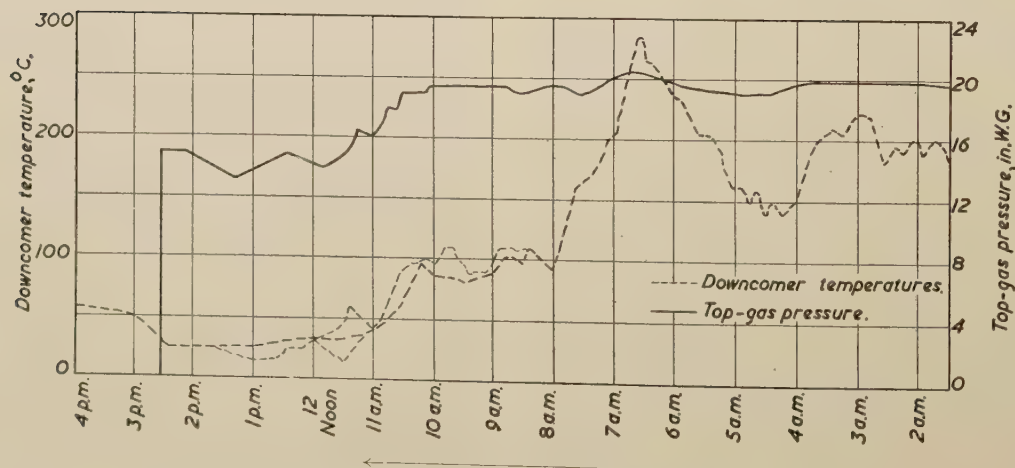


FIG. 1b—Records of the blow-out (see Fig. 1a)

ing 40.18 cwt. (4500 lb.), or a total dump from the large bell of 160.71 cwt. (18,000 lb.). The total number of charges of ore dumped into the furnace during the period from 6.0 A.M. to 2.30 P.M. was 62, and the operation was performed on a regular charging basis, the last dump being made 15 min. before the blast was finally taken off. The total weight charged was 498 tons.

At this point it is noteworthy to remark that, as was expected, when the ore was finally raked out of the furnace it was perfectly calcined. Allowing for a calcination and moisture loss of approximately 33%, there should have been 332 tons of calcined ore. Actually only 320 tons were recovered, showing a loss of some 12 tons. This loss is accounted for by the fines blown over into the dustcatcher from the ore, and an immeasurable quantity was found in the hearth of the furnace, at and below tuyere level, mixed with fine coke and also mixed with the solid slag in the hearth to tapping-hole level. All the calcined ore was graded through 1-in. forks, there being 290 tons of ore above 1 in. and 30 tons through 1 in. The descent of the stockline level was most even and regular, and no slips of the burden were noticed during the operation. There were no gas ticks when the cold ore was dumped from the bell into the furnace, as is sometimes noticed when cold material is dumped into the hot top of a furnace when blowing-out, and the furnace is worked as if normal operation was in progress.

After a review of the operation of the furnace during blowing-out, in conjunction with the amount of raw ore charged and the condition inside the furnace shaft and hearth when dismantled, it is possible to state that in this instance rather more raw ore than was necessary may have been used, although a reduction in the amount of ore charged in future blowing-out operations may have to be accompanied by a further reduction in blast volume and pressure; this procedure may not give as clean a blow-out as that attained and in consequence may leave a larger salamander in the hearth, the cost of removal of which might exceed that of raking-out and loading-up the extra quantity of calcined ore.

The hot-blast temperature during the blow-out was not altered in any way, a straight-line temperature of 550° C. being maintained as near as was practicable until the operation was complete.

The iron tapped out on each cast was quite normal and hot, as can be seen from the following data:

Time of Cast	Si, %	S, %	Mn, %	Weight.	
				Tons	Cwt.
7.30 A.M.	1.36	0.040	0.80	74	16
10.20 A.M.	1.32	0.035	0.86	52	17
2.45 P.M.*	1.16	0.050	0.78	66	1

* Final cast.

The reduction in hot-blast pressure, top-gas pressure, and top-gas temperature continued progressively as the air volume was reduced with the lowering of the stockline in the furnace (see Fig. 1). A rise in the top-gas temperature did occur during the charging of the first four charges of ore, after which a progressive decline in temperature was recorded until the blast was taken off the furnace at 2.45 P.M., when the temperature of the top gas was only 27° C.

The top-gas temperatures are normally recorded in the four offtakes at the top of the furnace. A straight-line temperature at the four offtakes was registered until 8.30 A.M., when there was a slight variation on three offtakes until 1.30 P.M., after which a straight line was again recorded on all the offtakes until the blast was finally taken off the furnace.

The furnace was operated as in normal circumstances, all the gas being consumed as cleaned from the gas-cleaning plant up to the end of the blowing-out period.

The gas analyses, as sampled from the furnace top, were as follows:

Time	CO, %	CO ₂ , %	H ₂ , %
8.00 A.M.	27.50	13.90	2.00
9.00 A.M.	26.90	16.00	2.63
10.00 A.M.	25.70	18.00	3.17
11.00 A.M.	25.50	18.60	3.40
12.00 noon	25.90	18.00	3.86
2.45 P.M. *	26.80	16.60	4.70

* Immediately before the blast was taken off.

The gas was of course mixed with the gas from another furnace operating at the time, and no ill effects in burning the gas were experienced. The condition of the tuyeres at the end of the operation was very good, there being no signs of blackening or chilling-off. When the furnace was taken off blast and opened up, there was only 1-1½ ft. of coke left above the tuyeres. The stockline was down by 46 ft.

When the blowing-out and the last cast had been completed, steam was turned into the dust-catcher, which was kept sealed with steam for about 8 hr. No bleeders or doors on the dust-catcher were interfered with in any way.

Whilst the furnace was still on a wind volume of 18,000 cu. ft./min., the water seal was filled to isolate the furnace from the crude-gas system and, as soon as the top pressure began to rise, the bleeders on the furnace were opened to relieve the gas pressure. The mixer valve was then closed and the main furnace valve was closed as the relief valve on the cold-blast main was opened, after which the stove valves were closed. There was still an air volume of 4000 cu. ft./min. passing through the cold-blast main and out through the

relief valve until all the blow-pipes were dropped, completely isolating the furnace from the hot-blast main. Not until this stage had been reached was the turbo-blower allowed to be stopped, thus preventing any possibility of gas passing into the cold-blast main. Work was at once commenced on pulling out the tuyeres and coolers, and no difficulty due to back pressure of gas through the tuyere openings was experienced. Water was then turned into the hearth through the cooler openings, the steam passing through the calcined ore and out of the bleeders, when the top temperature recorded was in the neighbourhood of 56–60° C. This steam from the cooling of the hearth also helped in cooling-down the calcined ore in the bosh and reduced the dust during the raking-out of the ore.

The material in the hearth from the tuyere level to 2 ft. 3 in. below the level of the tapping hole was quite easy to remove, as it consisted entirely of small coke with fine ore dust, partly mixed with slag, the whole of which was loosened by air picks and thrown out with shovels. There was a distinct dividing line between the material in the hearth and the remaining salamander, which had a flat surface over its entire area. The amount of salamander left in the hearth in the form of clean solid iron, which had to be broken up by explosives, was approximately 7 tons.

When the operation was reviewed it was

considered that the results rather more than justified the favourable expectations, and it may be presumed that the procedure may be improved upon by further trials in the future.

CONCLUSION

With the variety of possibilities in blowing-out methods in the operation of blast-furnaces, many methods which can be very efficient and successful can be worked out to a final conclusion, with safety to plant and personnel brought to very fine limits.

Science and engineering have put at the command of the blast-furnace operator resources undreamed of by his predecessors. We will, I trust, keep our wonderful opportunities in mind and do our utmost to advance blast-furnace practice. In no branch of industry is the exchange of experience more helpful and necessary to progress than in blast-furnace operation.

ACKNOWLEDGMENTS

The author wishes to express his thanks to the Chairman and Directors of Messrs. Richard Thomas and Baldwins, Ltd., for permission to publish this paper, and also to the staffs of the blast-furnace and laboratory departments for their valuable assistance during the period of operation.

Appendix—BLOWING-OUT No. 3 BLAST-FURNACE AT PARK GATE*

By J. W. Houghton†

WHEN Mr. Fowler introduced the blowing-out principle described in the foregoing paper, we at Park Gate were very much impressed by the possibilities offered and, as we were at the time considering blowing-out one of our furnaces, decided to adopt a similar method. In the past it had been customary to use limestone for the blow-down, a method which was considered to be very safe but which was always attended by the objectionable lime dust during the subsequent raking-out. We had no fully detailed description of a blow-out using only ironstone, so we decided to use as small a quantity as possible, while ensuring that sufficient material would remain in the furnace at the end of the blow-out to give a stock-line in the barrel of the furnace. A quantity of 150 tons of ironstone was actually used, in a furnace having a nominal volume from tuyeres to stock-line of 11,900 cu. ft.

Fig. 2 is a composite chart showing all the data

obtained during the blow-out. The full wavy line represents the temperature in the downcomer from the top of the furnace to the dustcatcher. The dotted wavy line represents the temperature in the bleeder and should be ignored, because, although it was endeavoured to keep the bleeder closed, it leaked slightly and allowed a small amount of gas to go up all the time, so that the temperature followed the other line very closely.

Water sprays were put in two of the test-rod holes, with water coupled up for use in case of emergency, but no water was used during the blow-out.

Blowing-out commenced at 5.00 P.M. (Friday, 3rd May, 1946) with a top temperature of 200° C., a blast temperature of 600° C., a wind volume of 16,250 cu. ft./min., and a furnace depth of 14 ft.

* Received 22nd September, 1946.

† The Park Gate Iron and Steel Co., Ltd., Rotherham.

A Leicestershire ironstone having the following analysis (as received) was used:

Iron	...	...	...	30.5%
Silica	...	...	...	11.0%
Lime	...	...	...	1.8%
Alumina	...	...	...	6.5%
Moisture	...	...	...	15.0%

It was decided that charging should be kept as regular as possible, and this was commenced at 5.40 P.M. with 6-ton rounds (30 cwt. per skip, 4 skips per round) and was continued in this way until 11.10 P.M., when, the top temperature remaining steady, the quantity was reduced to 3-ton rounds (15 cwt. per skip, 4 skips per round).

little water was introduced at the tuyeres to deal with the dust, but this was not very troublesome. There was apparently very little disintegration of the Leicestershire ironstone in the furnace, and it was interesting to find that most of the ore came out yellow, being by no means completely calcined, particularly in the upper part of the bosh. The ore was charged as run-of-mine with a large number of lumps in it, and many of these lumps, when they fell on to the furnace stage, cracked open and steamed, showing that all the original moisture had not been driven off. It is considered that a considerable proportion of the ore charged would not attain as high a temperature as that obtaining

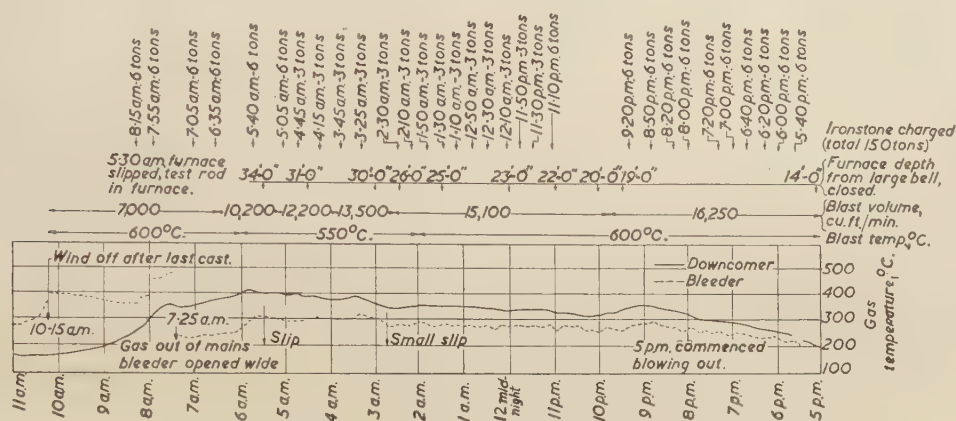


FIG. 2—Composite chart showing data obtained during the blow-out

At about 2.30 A.M. (Saturday, 4th May) a small slip occurred, and, in order to correct the rise in temperature which followed, the blast temperature at the tuyeres was lowered from 600° to 500° C. It was thought that, under the existing conditions, lowering the blast temperature might cool the top, but events followed the normal temperature rule that when the blast temperature is lowered the top temperature rises slightly. Another slip occurred later, and the blast volume was reduced to 10,200 cu.ft./min. It was suspected that the furnace was scaffolded—it had been on for 11 years—and that some of the slipping was due to scaffold coming away. On raking-out this was found to be the case, some large scaffolds being found down in the hearth.

Blast was taken off the furnace at approximately 10.15 A.M. on Saturday, 4th May, and raking-out commenced at noon on Sunday, 5th May. The condition of the furnace was such that after opening-out the tuyeres, the ironstone ran from the furnace just as from a calcining kiln. The only difficulty experienced was where scaffold had fallen in front of the tuyeres during the blow-out. This material made opening-out rather difficult. A

in the middle of a calcine clamp or kiln. The highest temperature of the outgoing gases was 400° C., which would be below calcining temperatures.

All the ironstone was removed from the furnace by Wednesday, 8th May, and only the scaffold, with some fused material adhering to it, was left above the tuyeres. The ironstone was charged straight into the other furnace operating at the time.

With regard to the disintegration of Leicestershire ironstone, we had expected to find that this had taken place to some extent, along with carbon deposition. There was, however, little or no evidence that disintegration had occurred, even in the hotter, lower part of the ore blank. This was rather surprising in view of some experiments that were carried out on this type of ironstone with a view to obtaining data regarding its character after calcining. On one occasion we put approximately 6 cwt. of the ore on a plate in an annealing furnace at a temperature of 850–900° C., but omitted to tell the operators to maintain an oxidizing atmosphere; when the ore was taken out after 20 hours' heating, most of it was in the form of powder. There were some 2–3-in. lumps present, but they

TABLE I—*Analysis of Leicestershire Ironstone after Calcining*

	As Received, %	After Drying at 100° C. %	After Calcining at 950° C. (in Lab- oratory), %	After Calcining in Annealing Furnace,* %
SiO ₂	10.82	14.00	16.50	20.20
FeO	0.79	1.03	1.22	22.80
Fe ₂ O ₃	40.20	52.00	61.50	34.80
Al ₂ O ₃	8.40	10.87	12.87	14.30
CaO	2.32	3.00	3.55	2.80
MgO	0.61	0.79	0.93	0.86
H ₂ O (com- bined)	11.52	14.90	...	...
CO ₂	0.46	0.60	...	...
H ₂ O	22.70	...	...	0.60
Fe (total)	28.75†	37.20	44.00	42.20
S	0.026	0.034	0.040	0.14
P	0.71	0.92	1.08	1.09

* Sample from clamp with 7% of coal.

† Wet.

had no strength and readily went to powder. Another trial was then carried out in the laboratory on a very much smaller sample in an oxidizing atmosphere and the ironstone remained more or less unchanged, except that it was completely calcined and had the characteristic colour of calcined stone. Table I shows the analyses of the ironstone thus treated. We can only suggest that

considered, and it was decided to take regular gas samples to check this. Table II shows these gas analyses, which indicate that no free air was blown through the burden during the whole period of the blow-out. Gas was kept in the common main throughout the whole period, and was used along with the gas from another furnace without any difficulties. The analysis of the gas was normal all the way through; the CO content had been high for perhaps a year. The furnace ought to have been blown-out some time before and probably would have been if war requirements had not made it essential to keep blowing; in consequence, the furnace had used considerably more coke than it should have done.

In conclusion, we are quite satisfied that this method of blowing-out gives easy control of the furnace throughout the blow-out period. The fact that gas can be kept in the mains up to the time that the furnace is taken off blast for the last cast has many advantages, and that all the ironstone can be charged back into stock or direct to another furnace is also attractive from the savings so obtained.

We feel that Mr. Fowler has filled a decided gap in the available blast-furnace information and that the subject matter in his paper will be of great interest to all blast-furnace operators, and

TABLE II—*Analysis of Gas Samples Taken during the Blow-Out*

Date	Time of Sampling	CO ₂ , %	CO, %	H ₂ , %	CH ₄ , %	N ₂ , %	O ₂ , %	Calorific Value, B.Th.U/cu.ft.
3/5/46	5.30 P.M.	5.2	33.2	2.0	0.20	59.5	nil	115
	10.00 P.M.	6.6	31.8	1.7	0.20	59.7	"	109
	11.00 P.M.	7.0	31.4	1.6	nil	60.0	"	106
	12.00 mid- night	6.2	32.0	1.5	nil	60.3	"	107
4/5/46	1.00 A.M.*	6.6	32.4	1.3	nil	59.7	"	108
	2.00 A.M.	7.6	30.6	1.2	nil	60.6	"	102
	3.00 A.M.	6.6	31.4	1.7	nil	60.3	"	102
	4.00 A.M.	6.8	31.0	1.7	nil	60.5	"	105
	5.00 A.M.	7.6	30.6	1.9	nil	59.9	"	104
	6.00 A.M.†	6.8	30.4	2.5	nil	60.3	"	105
	7.00 A.M.	7.4	29.8	2.9	nil	59.9	"	105
	8.00 A.M.	10.0	27.0	3.2	0.20	59.6	"	99
	9.00 A.M.	9.2	27.4	2.9	nil	60.5	"	97

* Just after casting, blast off.

† Furnace slipped at 5.30 A.M.

the ore in the blowing-out blank was sufficient to keep the temperature of the blast-furnace gases below the critical point at which carbon deposition takes place. This is in effect what we set out to do when we adopted this method of blowing-out.

Before blowing-out was commenced the possibility of free air being blown through the stock towards the end of the blow-out period was

particularly to those who are for the first time being responsible for blowing-out a furnace.

Acknowledgment

The author wishes to express his thanks to the Directors of The Park Gate Iron and Steel Co., Ltd., for permission to publish the above record.

SHREWSBURY LETTERS

A CONTRIBUTION TO THE HISTORY OF IRONMAKING*

By DR. H. R. SCHUBERT†

SYNOPSIS

A collection of letters preserved in the Central Library of Sheffield gives information of ironworking on the estates of the Earls of Shrewsbury in the sixteenth and seventeenth centuries. To make use of the timber in the Earl's extensive woods in Shropshire a furnace was erected at Shifnal, and a forge and two fineries at Lizard, in 1564. Between Goodrich and Whitchurch, in Herefordshire, iron was manufactured as early as 1543. The Manorial Court Rolls of Goodrich Castle contain many details as to ironmaking, e.g., monthly output, prices, financial stringencies, etc. Some of the letters show the great care taken for the preservation of woods, especially in the nearby Forest of Dean, with the personal intervention of King James I. First evidence of a forge at Higham, near Chesterfield, in Derbyshire, dates from 1578. In 1608 a new furnace and forge were erected on the Earl's Kimberworth estate in the district of Sheffield. Accounts dated 1574 and 1585 report on steel imported to Sheffield for the Earl's use, and a letter of 1595 mentions delivery of Sheffield knives with handles made of wood from the root of the box tree, called "doodgens," such as are spoken of in Shakespeare's "Macbeth." All these letters were given away by one of the Earl's descendants as papers of "inferior importance."

ONE of the great nobles in the reign of Queen Elizabeth was George Talbot, the sixth Earl of Shrewsbury, who lived from 1528 to 1590. He is well known in history as the custodian of Mary, Queen of Scotland, with whose custody he was entrusted by Queen Elizabeth for more than fifteen years.¹

The Earl was one of the richest men in England. His wealth was based on his extensive estates, mainly in the counties of Yorkshire, Derbyshire, Shropshire, and Herefordshire. He also knew how to develop their resources, and for this reason he was interested in the industrial improvements which characterized England's economic life in the sixteenth century. A new impetus was given to the iron industry on his various estates, as is shown by a collection of letters from his stewards and bailiffs, preserved in the Central Library of Sheffield.²

In the middle of the sixteenth century the states held by the Earl in Shropshire were well wooded. There was not much chance, however, of selling wood at a reasonable price. The first

letter of the Sheffield collection, written from Whitchurch in Shropshire and dated April 11, 1562, shows the difficulty of selling profitably. "All over the country," the bailiff writes, "the wood could not be sold the thousand at 20 shillings a tree." He had travelled to various places and people were willing to buy, but, "when they understand the price they flee every man." They were not willing to pay more than 8s. 3d. per tree when sold by the thousand, instead of the 20s. the Earl demanded.

Though there was very little chance of selling large quantities of timber, there was still the possibility of making a good profit by converting wood into charcoal for ironmaking. Lizard, of the Earl's manor and parc of Shifnal, in north-east Shropshire, was chosen as a suitable place for erecting a smithy. That the supply of wood for charcoal burning was ample is shown by the fact that the woods of Lizard Hill were still supplying charcoal for the hammers at Lizard in the seventeenth century.³

* Received 16th August, 1946.

† University of Reading.

¹ "Dictionary of National Biography," vol. 55, p. 314-316. London, 1898.

² Sheffield Central Library, 3 F.M.2 (beginning with 1549 and extending well into the seventeenth century).

³ Public Record Office, "Exchequer Depositions by Commission, Mich. 5, Charles I., No. 30." See also "Victoria County History of Shropshire," vol. I, p. 460, London, 1908.

The prospects of getting sufficient quantities of iron ore were, however, less favourable. The nearest mine was at Snellshill, north-west of Shifnal and east of Wellington. Thomas Goslyng viewed the site selected for the smithy, and also the mine at Snellshill, and liked the place for the smithy very well, "doubting nothing but only lack of stone in continuance of years." For the securing of future supplies, Andrew Corbett was approached as having a mine of ironstone adjoining the smithy place. The bailiff, Robert Swyste, also recommended the acquiring of another mine—one belonging to the Earl of Arundel—in the neighbourhood.

The smithy at Lizard was erected soon afterwards, and a furnace was built near Shifnal early in 1564. On July 12 Thurston Woodcock reports to Earl George that he hopes the furnace "will begin to blow upon Thursday next," and adds that the "two new fineries at the smithy in Lyssyard which Monslow made, will be finished not long too."

With such an extension of the ironworks, the smithy previously erected at Lizard proved to be inadequate. "The workmanship of the dam, the gate (flood-gate), the great wheel and divers other things there were nought," as Woodcock reported. He was therefore compelled to have them transferred and "to make much thereof new." These remarks suggest that the smithy had to be built anew and turned into a forge more adequate for amplified production. Accordingly, Woodcock calls this new forge the "great" smithy.

The ironmaster who introduced the finery process by erecting the two new fineries (probably a finery and a chafery for refining the wrought iron) was Monslow or Monsloe. The Monsloes had been ironmasters in Shropshire long before. One Thomas Monsloe was tenant of a smithy at Shirlot, in the parish of Much Wenlock, before 1531.⁴

The workmen employed at the new ironworks numbered forty in all, not too high a figure considering that it includes all the workers employed, beginning with those cutting timber, burning charcoal, and getting ore, and ending with those engaged on the finished products ready for sale.⁵ A general idea of the wages the

⁴ Calendar of the Patent Rolls, Philip and Mary, vol. II, p. 21. London, 1936: H.M. Stationery Office.

⁵ At the double furnace and forge in the Forest of Worth, in Sussex, the number of workmen employed in 1549 was thirty-three. (E. Straker, "Wealden Iron," p. 462. London, 1931: G. Bell and Sons, Ltd.)

Earl's workmen were paid is to be gathered from the memorandum book⁶ of William Dickenson, bailiff of Hallamshire in Yorkshire, which covers a period from 1574 to 1576. Dickenson remarks upon "workmen engaged for any work the Earl will set them upon" getting 12*d.* per week and meat and drink, and, "if they stay at Christmas they will get their wages. But, if they go to their friends in that time, to have no wages," *i.e.*, no paid holidays.

Of course, skilled workers were paid on a different basis, *e.g.*, in 1574 a bloomsmith got eightpence for each bloom he had blown, and ten



Miners' tools, ore barrows, and baskets

shillings a year for his coal. In addition, he "had a cow kept winter and summer." With such highly skilled workers as founders, special agreement was made as to wages and allowances, but these were not always paid regularly. Thus, in December 1609, Thomas Browne, the founder, had to send a "humble petition" to the Earl for payment of the money due to him since the previous May.

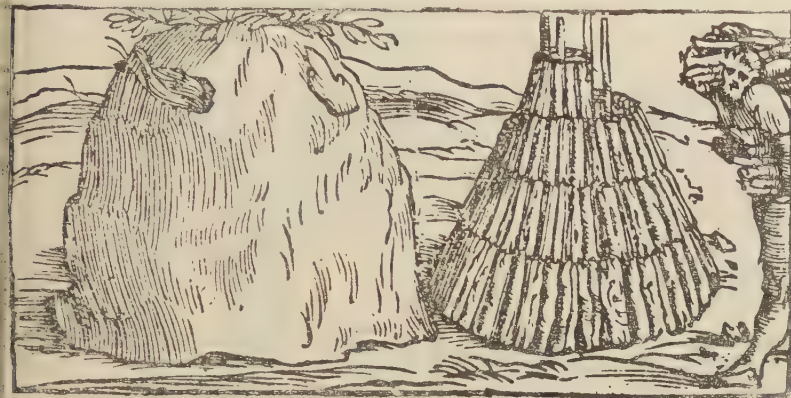
According to Woodcock's letter, things appeared to go very well at the new ironworks near Shifnal, and at Lizard. But the possible scarcity of ironstone, indicated before the erection, was still a potential danger threatening prosperity, as Woodcock refers to the great need of getting ironstone before winter, to keep the furnace blowing. Another threat to production was the lack of oxen for carrying charcoal and ironstone. Dickenson, the bailiff of Hallamshire, sent 36 steers to Shifnal in October 1574, but such numbers of oxen were not always available, especially where there was a lack of grass for cattle-feeding. Thus, in 1595 (May 19), Anthony Roberts writes to "his good friend" the steward of the Earl of Shrewsbury's household in London that he cannot "get oxen sufficient for the carriage of iron-stone and charcoal," owing to the lack of grass. The position was the same at Tankersley

⁶ Preserved in Sheffield Central Library.

mine, which supplied the Shrewsbury furnaces at Kimbersley and Wadsley, near Sheffield. So, Roberts fears, "things will not fall out as they have done."

Thomas Goslyng, who viewed various mines in Shropshire and the place selected for a smithy, was a man from the Earl's manor of Goodrich, in Herefordshire. Remnants of an ancient ironworks built in the first half of the seventeenth century⁷ on the river Wye, between Goodrich and Whitchurch, are still in existence and are known as "Old Forge Barn."

In the Court Rolls of the Manor we find ample



Construction of charcoal piles

evidence of ironmaking at this place, beginning with 1543.⁸ The ironmaster was Robert Sybrance or Sebrays. On the 10th of June, 1543, he sold a "gad" of iron at the price of 3s. 8d. As a "bar or piece" of iron was sold at 20d. in 1554, a gad had two such pieces, each weighing 1 cwt., in 1547.

From March to May, 1544, there is evidence of a monthly output of iron amounting to 2 tons, "blowed and made" at the works. As the ironworks of the early sixteenth century generally worked for not more than nine months of the year because of lack of water-power, we may assume an annual output of about 18 tons. As iron was "blown" and bars were forged, we may also assume that the method applied was still the direct process of ironmaking used in the bloomeries of previous centuries. This is confirmed by the fact that iron of better quality had to be imported, *e.g.*, from Spain (in 1547).⁹

A furnace in the district of Goodrich is first mentioned in a letter sent from Goodrich Castle on January 12, 1575, to Earl George by his second

⁷ "An Inventory of the Historical Monuments of Herefordshire," vol. I, p. 81. London, 1931.

⁸ The Court Rolls from 1507 to 1838 are preserved in the public library at Hereford; Thomas Goslyng is frequently mentioned.

⁹ "*Unam barram ferri Hispanie*"; Court Rolls of 1549-1550.

son, Gilbert Talbot,¹⁰ who became the seventh Earl of Shrewsbury after his father's death in 1590 and who lived until 1616.

The financial results of Robert Sybrance's activities were apparently not quite satisfactory. In 1544 he was in debt and unable to pay expenses incurred by some of his workers for food. To some extent Sybrance was himself responsible for his bad position; as happened with many of these old-time ironmasters, he was so much absorbed by the technical part of his work that he neglected his duties as to the keeping of necessary accounts. The Earl, desiring to have pecuniary gains from his ironworks, took a grave view of the situation and appointed John Dewe as a supervisor. As Dewe could not induce the ironmaster to keep strict accounts, and as there were debts to be paid, he felt that he had to seize the iron produced at the works. But Sybrance was not the man to yield easily, and Dewe was not able to have the iron carried away without using force and weapons (*vi et armis*).

However, Sybrance continued making iron, but in 1553 he again contracted debts. This time, together

with Thomas Henant—a farmer at the village of Penrick, within the manor of Goodrich—he borrowed £20 (a fair amount of money in the sixteenth century) from a clergyman. This is the last evidence of this ironmaster's activity, but iron-making did not cease at the works. In a letter of the Sheffield collection, sent to the Earl from Goodrich Castle on 20th January, 1563, George Walworke wrote: "I have some workmen at hand with my work here at Goodrich, and for the most surety will send 2 or 3 loads of iron-stone into Wales, to the founder there."

Quite near to the works was the Doward, a group of well-wooded hills between Whitchurch and the river Wye. These wooded hills mainly provided the ironworks with charcoal and ore. A "coal pit" is mentioned in the Manorial Court Roll of October 21, 1551.

The iron produced at the works was certainly absorbed to a great extent by the demands of agriculture and building on the Earl's estate, and also by the village smiths. Nail-making was apparently a flourishing trade in the district. On the 10th of December, 1550, "John Smith called Bagster, of Whitchurch, sold 92 pounds of iron nails to the Mayor of the town of Monmouth at 3 pence the pound."¹¹

¹⁰ The letter is published in "Historical Manuscript Commission," 15th Report, Appendix II, "The Manuscripts of J. E. Hodgkin," p. 33, London, 1897.

¹¹ Court Rolls of 1552 (November 23).

In 1609, George Moore¹² was in charge of the administration of Goodrich. In a letter of the 26th of April he reports on a weir in the river Wye, near the Doward hills, which had been carried away by a great flood following an extraordinarily severe frost. Hancock, the farmer of the weir, was asking for timber for the rebuilding of it. An undated letter of the same time, dealing with the weir, points out the disadvantage caused to the forge between Goodrich and Whitchurch by "pounding up the water so high upon the forge that not one bar of iron could be made in 12 weeks." From the same letter we learn that the iron manufactured at the forge was sent by boat to Bristol and Gloucester.

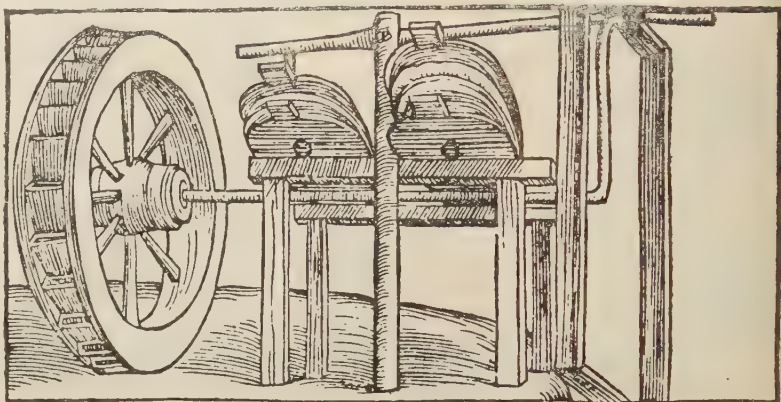
George Moore was a man with a keen eye for everything going on in the iron industry. He informed the Earl of plans for the erection of new ironworks in the Forest of Dean, "there being divers good rivers and mine or iron-stone in all parts of the same and the woods so stately and such planted, as will continue 6 furnaces and as many forges at least 20 or 30 years." He recommended that some of the trees of the Forest, marked for sale, be acquired, as "some parts of the same woods are very convenient" for the Earl's ironworks at Goodrich, there "being no wood in Your Honours lands that will be very fit to coal 12 or 16 years." It is doubtful whether such timber was obtained from the Forest of Dean, as King James I was strongly advised that more profit could be got by the conversion of wood to charcoal for making iron than by selling timber.¹³

It is interesting to learn from one of the letters, dated January 1, 1608, how much personal interest King James took in the preservation of the Forest of Dean. When he had some of the surveyors of the Forest before him, he restricted the number of trees to be taken, and ordered that "upon every such taking young trees to be put in their places."

A similar care for the preservation of woods was taken when the ironworks at Shifnal and Lizard were built. When Monsloe, the ironmaster in charge of building and the supply of raw material, had the trees at Lizard cropped, it was done in such a way that many of them were

left intact, and many of those that were cropped he had "cut in the middle, so that the spring thereof is not to be locked."¹⁴

That such care was taken proves that the various legal acts passed in the course of the sixteenth century for the preservation of woods and forests were observed and that they successfully counteracted the destruction of timber which followed the dissolution of the monasteries by Henry VIII.¹⁵ The preservation of timber—the only source of fuel for iron smelting—was in the ironmasters' own interests. The numerous inquisitions made in the sixteenth and seventeenth



The operation of bellows by an overshot water wheel

centuries as to the state of the woods in all the counties of England are a striking symptom of the general interest taken in the nation's wood resources.

A letter dated 10th December, 1578, sent from Derby to the Earl of Shrewsbury by Robert Bainbridgeth (a merchant with wood and iron ore), refers to a forge near Higham in North Derbyshire, south of Chesterfield.¹⁶ At the time of the letter the forge was owned by Bainbridgeth, but was worked by one of the Earl's employees. The letter also refers to an ironmill—owned by the Earl himself—which is not named, but which was probably near the forge, as a fair amount of the iron ore delivered by Bainbridgeth

¹⁴ Letter of January 20, 1563.

¹⁵ G. J. Ch. Cox, "The Royal Forests of England," p. 73. London, 1905. As to the legislation sought for the preservation of the woods of England, see E. Lipson, "The Economic History of England," vol. II (third edition), p. 157. London, 1943: E. Straker ("Wealden Iron," pp. 109, 123, 126, 132) shows that the resources of wood in the weald of Kent, Surrey, and Sussex were well preserved in the sixteenth century, in spite of the frequent complaints about destruction. He also points out that the consumption of wood by iron smelting was much less destructive than was assumed by the various complainants, as orderly coppicing facilitated natural regeneration.

¹⁶ Earl George was in possession of the castle and manor of Chesterfield. (See "Inquisition post mortem," Public Record Office, C, 142, vol. 231, No. 106.)

¹² George Moore went into the King's service in 1615 and was still in it in 1617. He was an overseer or agent of the Royal ironworks at Cannop and Lydbrook, in the Forest of Dean. (Public Record Office, Exchequer Special Commissions, No. 3837.)

¹³ "Victoria County History of Gloucester," vol. II, p. 272. London, 1907.

was temporarily stored at the latter place. This letter provides the first evidence of ironworks belonging to the Earl of Shrewsbury in the Chesterfield district. Later, in 1588, the Earl was owner of smithies at Barlow, north-west of Chesterfield.¹⁷

Amongst the letters is an extract from an "Account Booke" about "the newe iron works at Kymberworth," near Sheffield, in Yorkshire. The extract mentions expenses "for building the forge and furnace" in January and March, 1608. A note at the back again refers to the "newe" ironworks. Unfortunately, the extract is very brief, and there are no further details as to building. However, the fact remains that a new furnace and forge was built at Kimberworth in 1608.

So far, the first evidence we have of a blast-furnace on the Kimberworth estate (which came into the possession of the Earls of Shrewsbury in 1553) dates from 1589. At this date the pig iron produced at the Kimberworth furnace was refined at the hammers at Attercliffe, no forge at Kimberworth itself being mentioned.¹⁸

An account dated July 16, 1585, refers to steel received for the Earl's use from Alderman Martin, in London. Richard Martin, Alderman of London from 1578 to 1602, was a goldsmith¹⁹; he also played quite an important part in the iron industry. From 1570 onwards he was a lessee of the wireworks at Tintern Abbey, in Monmouthshire, the lease being renewed for fifteen years in 1581.²⁰ The whole amount of steel received was 25 barrels, costing £13 6s. 8d. each. This is a valuable contribution, as we have not very many records of steel being imported to Sheffield. In his memorandum book, William Dickenson reports the receipt of six barrels of steel from Bawtry on the 8th October, 1574. Bawtry was one of the chief trading centres of the Midlands for importing steel. To Bawtry it came by way of the rivers Trent and Idle, from the seaport of Hull.²¹ The steel "was layd in the stawre (store) house at Sheffield Castle." Almost the entire contents of five of these six barrels were distributed amongst various employees of the Earl in the course of the year following the storing. There is no special account of what the steel was used for, except for one item saying that 60 gads were delivered to mills at Sheffield and Attercliffe, for mending. As

the account of 1585 begins with "Receyved for his Honors use," the 25 barrels of steel were evidently disposed of in the same way as the six barrels of 1574, viz., on the Earl's estates, for the making of implements or for the repairing of the iron parts of a mill's outfit.

Reference to Sheffield cutlery is found in a letter dated May 29, 1595, sent by James Rawson to Earl Gilbert of Shrewsbury at his house in Broad Street, in London. Rawson writes regarding the delivery of two cases of knives sent to Earl Gilbert. One case contained "knives hefted in

doodgen," the other "knives hefted in hard horn," i.e., knives with handles made from the root of the box-tree, and knives with handles of hard horn. On account of its hardness, wood from the root of the box-tree was frequently used for making hilts of daggers, such as are spoken of in Shakespeare's "Macbeth" (Act I, Scene II).²² The price paid for both cases was 13s.

The letters of the Sheffield collection, sent to Earl George of Shrewsbury and his son Gilbert by various employees, give a good survey of ironworking on the extensive Shrewsbury estates in the northern and western counties of England. These letters were given to a collector of documents by a descendant of the Earl, as

they were thought to be of "inferior importance." This instance proves that papers unimportant for general history might be valuable for the history of the English iron and steel industries. Probably there are still in the possession of old families many unpublished documents which may be of great value in such a history.

¹⁷ "Victoria County History of Derbyshire," vol. II, p. 358. London, 1907.

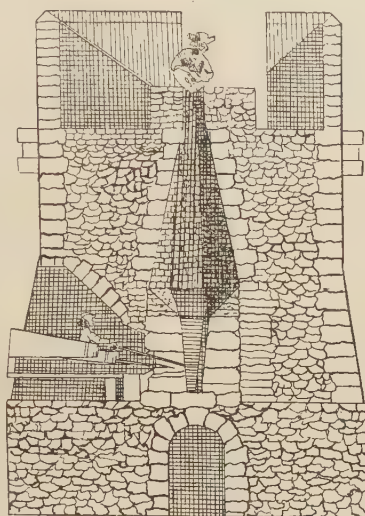
¹⁸ R. A. Mott, "Early Iron Making in the Sheffield District" (unpublished paper to the Sheffield Society for the Preservation of old Sheffield Tools, 1946, pp. 17-18).

¹⁹ "Dictionary of National Biography," vol. 36, pp. 290-291. London, 1893.

²⁰ British Museum, Lansdowne MS. 76, and "Mineral and Battery Works," vol. I, p. 100.

²¹ G. J. H. Lloyd, "The Cutlery Trader," p. 336. London, 1913.

²² A. L. Maghew, "A Glossary of Tudor and Stuart Words," p. 124. Oxford, 1914.



Typical Blast-Furnace of the 16th-18th Century

The woodcuts illustrating pages 522 to 524 are reproduced from the "*Pirotechnia*" of Vannoccio Biringuccio, published, in 1942, by the American Institute of Mining and Metallurgical Engineers.

The Application to Shaping Processes of Hencky's Laws of Equilibrium*

By E. Siebel†

SYNOPSIS

The increase in pressure along slip lines, and the relationship between the mean pressure and the principal stresses as well as between the slip lines and the stress trajectories are discussed. Rules regarding the formation of slip lines are outlined. Slip-line systems and stress conditions on compression, and the resistance to flow between rough plates with constant and with varying friction at the compressing surfaces are analysed, allowing for the form of the free surface on compression. The gradual advance of slip layers in direct compression processes is explained and diagrammatically illustrated. Slip lines and stress conditions in cupping and related processes are described, and consideration is given to die friction and the cohesion of the metal. Slip lines and stress conditions in pressing processes are elucidated, followed by a discussion on the various systems of slip layers. The effect of work-hardening is explained mathematically.

IT was indicated by Prandtl¹ that the laws expounded by Hencky² concerning the properties of the slip-line families of plastic bodies can be adapted to the treatment of numerous problems of the plastic state. Based on these laws, the attempt will be made in the following to obtain some information regarding the conditions of stress prevailing in a number of shaping processes applied in practice.

Plastic deformation is brought about by the translation of slip layers lying in the direction of the greatest shear stress, and with plane deformations a system of slip lines is formed which is composed of two families of slip layers at right angles to each other (see Fig. 1). As found by Hencky² on studying the equilibrium conditions with constant shear stress K , the variation of the mean pressure p on travelling from A to B along a slip layer of the α family can be expressed by the following equation:

$$\Delta p_\alpha = 2K \cdot \Delta\beta = k_f \cdot \Delta\beta, \quad (1)$$

where $\Delta\beta$ is the angle through which the normal to the slip layer under consideration rotates from A to B; whilst $k_f = 2K$ represents the 'resistance to deformation'‡ which is taken to be constant (Fig 1). Correspondingly, on travelling from A to D

along a slip layer of the β family the following equation applies:

$$\Delta p_\beta = 2K \cdot \Delta\alpha = k_f \cdot \Delta\alpha. \quad (2)$$

Provided that the slip-line system is known, equations (1) and (2) allow, in the simplest possible way, the calculation of the variations of the mean

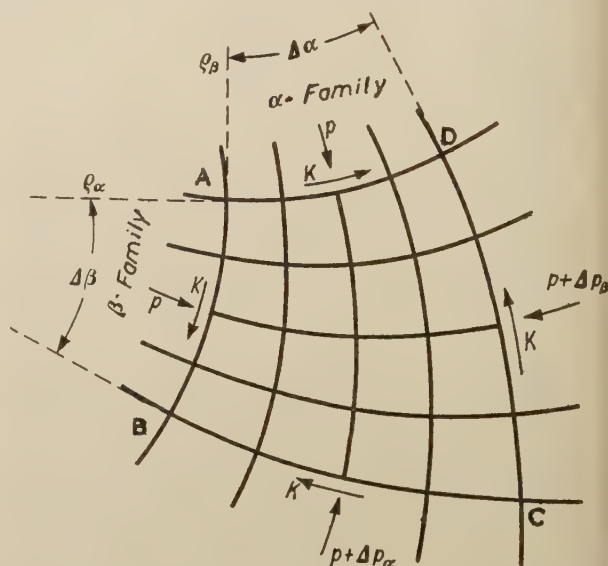


FIG. 1—Slip-line system with plane deformations

* Received 10th January, 1946.

† President of the Inspection of Materials Board, Dahlem, Berlin.

‡ This is the literal translation of the German term "Formänderungsfestigkeit," a definition of which has been given by the author in *Archiv für das Eisenhüttenwesen*, 1944, vol. 13, July-Aug. pp. 13-22; see Iron and Steel Institute, 1947, Translation Series No. 295.

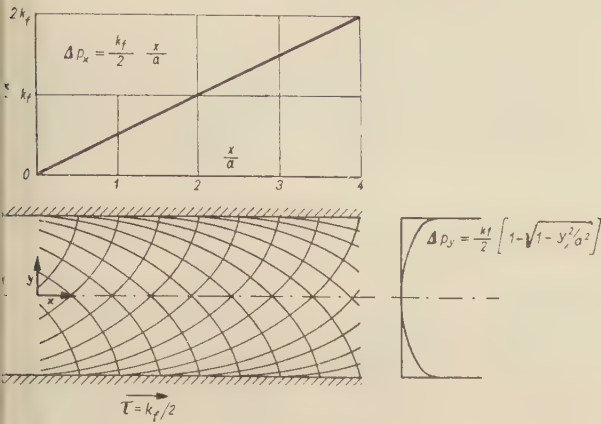


FIG. 2—Slip lines and stress distribution on compression between two parallel rough surfaces

pressure and, consequently, the variations of the principal stresses:

$$\sigma_1 = p + \frac{k_f}{2} \text{ and } \sigma_2 = p - \frac{k_f}{2}. \quad (3)$$

At the same time the slip-line system determines the principal-stress directions, since the trajectories of the principal stresses are throughout inclined at 45° to the slip lines.

As shown by Hencky,² with two-dimensional stressing the slip layers form two families of curves crossing each other perpendicularly in such a way that the tangents drawn to two curves of one family at the points of intersection with each curve of the second family form throughout the same angle with each other. Systems of curves obeying these conditions can easily be traced with the aid of the rules regarding the radii of curvature deduced by Prandtl,¹ the dimensions of the systems being frequently determined unambiguously by the boundary conditions. In cases in which no unambiguous solution seems possible, the one yielding the

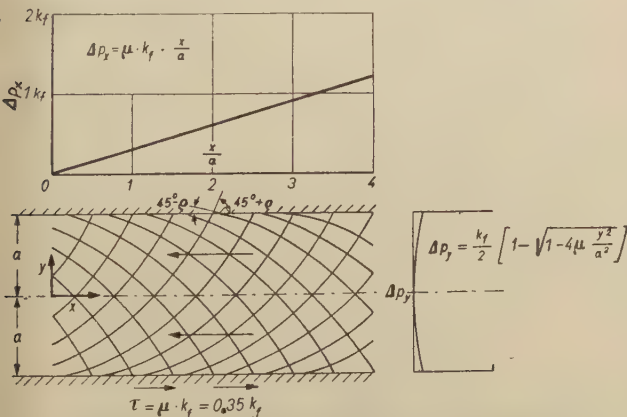


FIG. 3—Slip lines and pressure distribution on compression with constant friction, $\tau = 0.35 k_f$, at the compressing surfaces

smallest loads may be selected, as was suggested by Hencky.

DIRECT COMPRESSION PROCESSES

The slip-line systems and stress conditions of some compression processes carried out in practice will be discussed first. Prandtl¹ suggested a solution for the compression of a plastic body of small height h between plane and parallel plates for the case in which the roughness of the compressing surfaces is so great that no slip of the plastic material along these surfaces is possible (Fig. 2). This condition will usually be fulfilled in hot-compression processes, *e.g.*, on formation of the flash in drop-forging. However, in cold-compression, especially if this is carried out with the aid of a lubricant, the friction at the compressing surface is lower. If the assumption is made that the shear stress τ at the compressing surfaces has a constant value $\mu \cdot k_f$, a slip-line system as shown in Fig. 3 will be obtained, in which the slip lines at the compressing surfaces will throughout be inclined at angles $\alpha = \rho + 45^\circ$, and $\beta = \rho - 45^\circ$, the value of μ being $\tan \rho$. In the same way as in the solution suggested by Prandtl, the slip lines remain cycloids also in

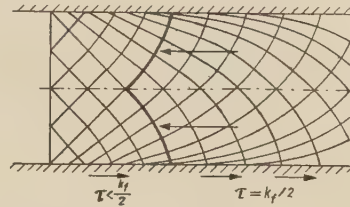


FIG. 4—Slip lines on compression with continuously increasing friction, τ , at the compressing surfaces

the present case, the mean pressure rising in proportion to the distance from the free surface. If the shear stress at the compressed surface does not remain constant, but rises continuously from zero to the maximum of $\tau_{\max.} = k_f/2$, the slip-line system presented in Fig. 4 is obtained in which the cycloids are transformed into straight lines. With this system of slip lines the free surface of the plastic body is bounded by a plane. If the shear stress rises suddenly from zero to $\tau_{\max.}$, the slip-line system of Fig. 5 will be obtained, the free surface AB being convex in this case. Such convex free surfaces are observed in all compression processes in practice.

Die-Forging

Körber and Siebel³ made a detailed experimental study of the slip-line systems formed on die-forging when only a small area of the bar being forged is exposed to the effect of the two dies being moved against each other.

In these experiments mild-steel bars were compressed between narrow dies until the beginning of flow, and the slip layers formed were rendered visible by etching according to Fry's method. Figure 6 gives a diagrammatic representation of the spread of the slip layers under increasing compression. At each of the two compressing surfaces a separate system of slip layers is formed first, which consists of two slip-line families originating at the edges of the dies. With increasing pressure the slip-line families spread more and more, and the two systems originating at the two compressing surfaces affect each other in such a way that, with further advance, the outer slip lines of each system run parallel to the outer slip lines of the opposite system. With regard to the stress distribution, the formation of the slip-line system described leads to the conclusion that, in the core of bars stressed in this way, tensile

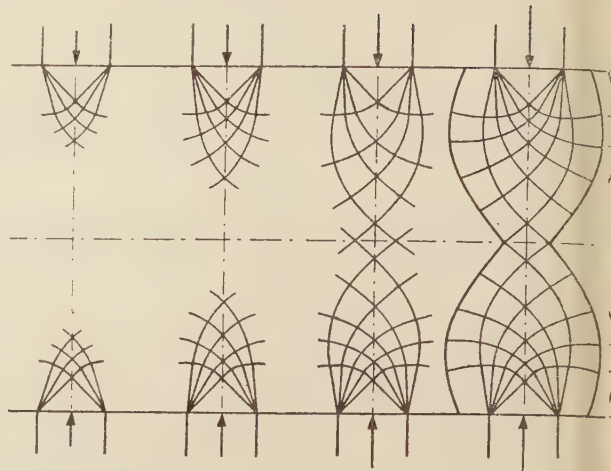


FIG. 6—Advance of slip layers in a bar compressed from both sides by narrow dies

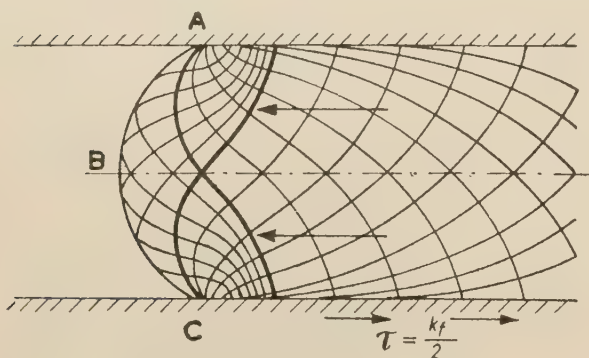


FIG. 5—Slip lines on compression with abruptly increasing friction, τ , at the compressing surfaces

stresses will act in the direction of the axis of the bar, which may lead to fracture.

On forging between wide dies the slip-layer system shown in Fig. 7 will be formed. On forging, such flow phenomena may be recognized at the side faces of the bars in the form of so-called percussion figures, increased cracking-off of scale and a rise of temperature being observed at such zones.

Rolling

If, on rolling with slight reductions, the areas of contact between the rolls and the rolling stock are small compared with the thickness of the stock, the stress conditions will approach to those of die-forging with narrow dies; and the slip-line systems formed will be largely in accordance with those on forging. The rolling process is distinguished from the simple die-forging process, however, by the fact that the rate of compression drops from a maximum at the roll

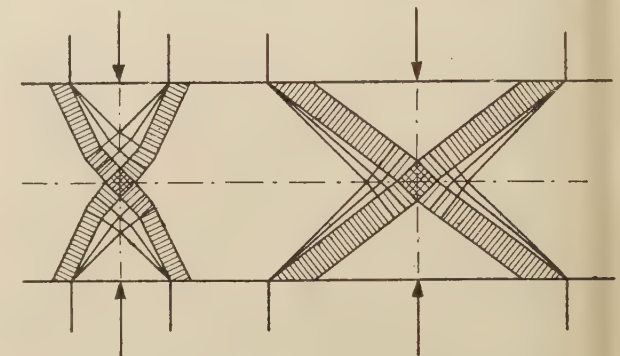


FIG. 7—Slip layers on drawing between wide dies

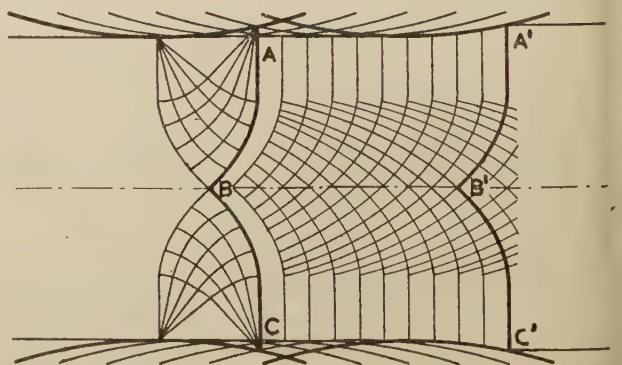


FIG. 8—Formation of slip lines on cold-rolling at low pressure

rolling process, as on die-forging, the pressure exercised is not fully effective in the interior of the rolling stock. In order to achieve an effect to some depth it is necessary to adapt the diameter of the rolls and the draft to the thickness of the rolling stock.

CUPPING AND RELATED PROCESSES

Slip-line systems may be used also in the study of the stress conditions in cupping processes, since here the condition of plane flow of the material is practically fulfilled in numerous cases.

Deep-Drawing

In deep-drawing, for instance, the circular cup is drawn inwards over the blanking die by means of the forming punch and is deformed by the combined effect of the radial tensile stresses σ_r and the tangential compressive stresses σ_t , buckling being prevented by means of the attached annular holder (Fig. 9 a). As shown by Fig. 9 (b), the slip lines must be inclined at 45° to the inner and outer edges, thus forming logarithmic

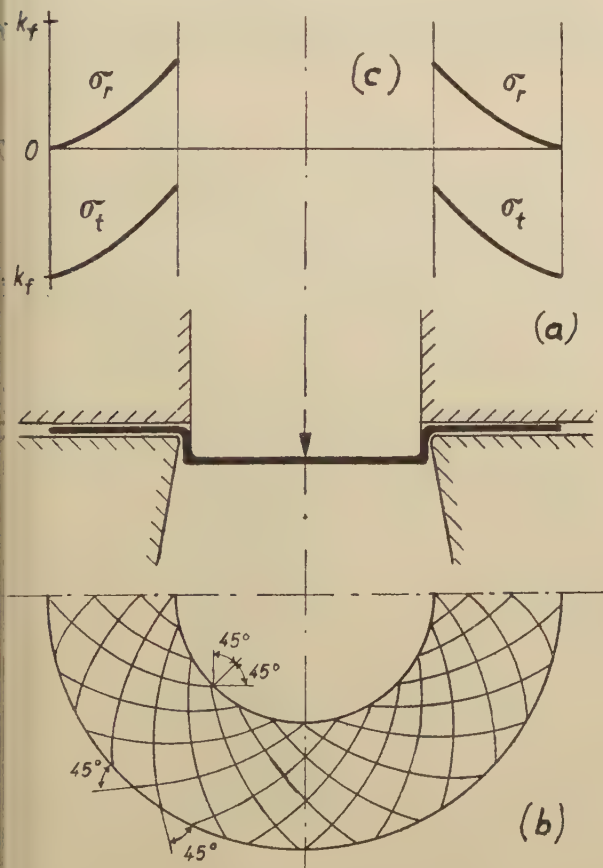


FIG. 9—Slip-line system and stress distribution on deep-drawing

spirals. Since the variation of the angle of a spiral of this kind, from the outer edge of diameter R to an arbitrary circle of diameter x , corresponds to the natural logarithm of the ratio of R to x , the variation of the mean pressure between R and x is given by :

$$\left[\Delta p \right]_x^R = k_f \cdot \log_e \frac{R}{x}. \quad (4)$$

This leads to the following values for the radial and tangential stresses (Fig. 9 c) :

$$\sigma_r = k_f \cdot \log_e \frac{R}{x}, \quad (5)$$

$$\sigma_t = k_f \left(\log_e \frac{R}{x} - 1 \right). \quad (6)$$

The same values were obtained by Siebel and Pomp⁴ when studying the equilibrium of forces in a body element bounded by radial and tangential sections.

Tube Drawing

The stress conditions in tube drawing correspond largely to those in deep-drawing. Here too, as shown in Fig. 10, a slip-layer system composed of logarithmic spirals is developed at the outer surface of the tube within the drawing die, deformation taking place under the effect of the longitudinal tensile stresses and circumferential compressive stresses, without any appreciable alteration of the wall thickness. During the process the longitudinal stress increases from zero at the entry of the die (original radius r_0) to :

$$\sigma_l = k_f \cdot \log_e \frac{r_0}{x}, \quad (7)$$

at a point of radius x , whilst the same tangential stress as on deep-drawing is obtained :

$$\sigma_t = k_f \left(\log_e \frac{r_0}{x} - 1 \right). \quad (8)$$

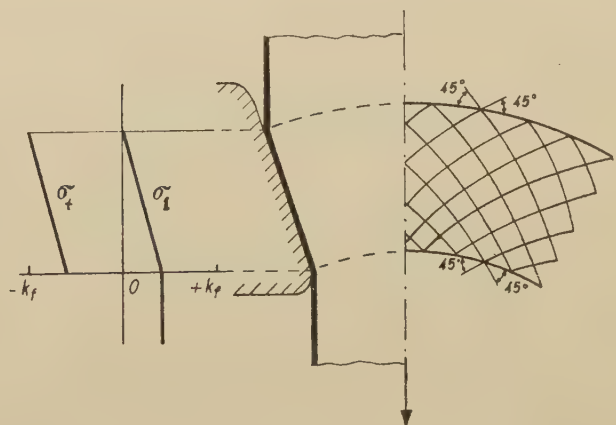


FIG. 10—Slip-line system and stress distribution on tube-drawing

By means of a simple study of the equilibrium the radial stress at the die wall can be calculated to be :

$$\sigma_r \sim \sigma_t \cdot \frac{s}{r}, \quad (9)$$

where s is the wall thickness of the tube.⁵

Drawing of Strip

On drawing strip through a rectangular die where the width of the strip is retained but the thickness d is reduced, the logarithmic spirals shown in Fig. 11 are obtained as a slip-line system if the friction at the die wall and the specific conditions due to the cohesion of the material at the die entry and exit are neglected. The longitudinal tensile stress is thus found to be :

$$\sigma_1 = k_f \cdot \log_e \frac{d_o}{d}, \quad (10)$$

whilst the transverse compressive stress amounts to :

$$\sigma_q = k_f \cdot \left(\log_e \frac{d_o}{d} - 1 \right) \quad (11)$$

It is possible, however, to take the drawing die friction into account in a simple way, the spirals forming angles of $45^\circ \pm \rho$ with the normal to the die wall in this case, as shown in Fig. 12. This leads to a more pronounced curvature of the slip lines and a correspondingly greater longitudinal stress combined with a decrease in transverse compressive stress. If the length of the die becomes very small compared with the thickness of the strip, as is the case in practice with small drafts and a quick taper of the die, the cohesion of the material at both ends of the

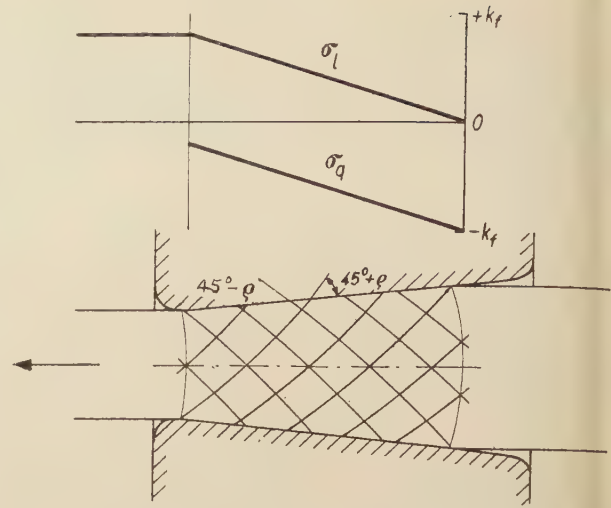


FIG. 12—Slip-line system and stress distribution with constant friction, $\tau = 0.1 k_f$, at the die wall

die greatly affects the stress conditions, so that the slip-line system will be very similar to that formed on die-forging between narrow dies, as shown in Fig. 13. In this case a non-uniform stress distribution and increased tensile stresses in the centre of the cross-section must be anticipated.

PRESSING PROCESSES

In addition to direct compression and cupping processes, pressing operations, especially extrusion and piercing, are of great importance in practice. By means of slip-line systems the attempt is made in the following to gain some information

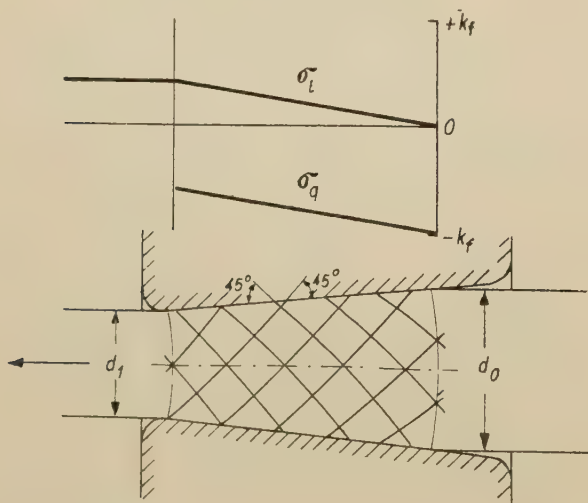


FIG. 11—Slip-line system and stress distribution in frictionless drawing

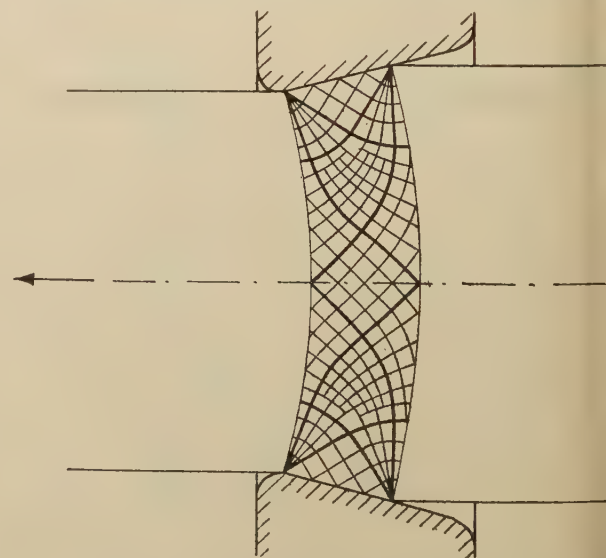


FIG. 13—Slip-line system on drawing with narrow zone of deformation

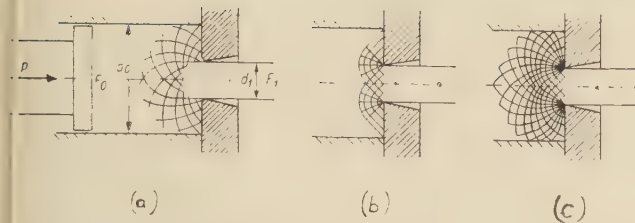


FIG. 14—Slip-line system on extrusion. (a) Logarithmic spirals; (b) straight lines and circles; and (c) straight lines, circles, and spirals

on the complicated stress conditions involved in these operations, the investigation being of necessity limited to plane deformation again.

Extrusion

With regard to the extrusion process, the assumption may be made that a slip-line system composed of logarithmic spirals is formed, as shown in Fig. 14(a). With this system the radial compressive stresses directed towards the centre of the die would rise from zero in the extruded bar to $p = k_f \cdot \log_e d_0/d_1$ at a distance $d_0/2$, d_0 being the thickness of the original cross-section and d_1 that of the final cross-section. Beyond the deformation zone, the pressure p acts in all directions. With a billet having a cross-section F_0 the compressive force required can be calculated to be :

$$P = F_0 \cdot k_f \cdot \log_e \frac{d_0}{d_1} \quad (12)$$

Measurements of the force required in experiments on the pressing of soft lead, carried out by Siebel and Fangmeier,⁶ showed that P varies in proportion to the natural logarithm of the ratio of the original to the final cross-section, so that the slip-line system traced will closely simulate the stress conditions actually prevailing.

There is also the possibility, however, that the stress-line system shown in Fig. 14(b) is developed. This corresponds to the conditions anticipated by Hencky¹ and Prandtl² when considering the advance of a cutting edge into a semi-infinite block, with the difference, however, that the flow of the material takes place in the opposite direction. In this system of slip lines the principal-stress trajectories at the exit opening of the die run parallel to the axis of the system. Accordingly the flow of the material takes place here in 'flow tubes' parallel to the axis, whilst with the slip-line system of Fig. 14(a) the metal flows towards the centre of the die. A further difficulty encountered with the latter system is that the frictional conditions at the front wall of the container are not taken into account. It is well known that between the edge of the die and the

container wall the metal lies in a dead zone and does not take part in the deformation, the boundary of the deformed region being formed by a slip layer. On the other hand, it must be expected that the deformed zone will extend beyond the limits drawn in Fig. 14(b).

If these conditions are taken into account the actual slip-layer system on extrusion will roughly correspond to that represented in Fig. 14(c). The compressive force P is then found to be :

$$P \cong (F_0 - F_1) k_f (1 + \alpha) \\ = F_0 \frac{d_0 - d_1}{d_0} k_f (1 + \alpha), \quad (13)$$

where α (i.e., the angle turned through) is presumably less than $\pi/2$ for small reductions and greater than $\pi/2$ for large reductions.

Regarding the flow of the material, the dimensions of the deformation zone lead to the conclusion that as the billet advances, the parts of its cross-section nearest to the axis will initiate the deformation. The originally flat cross-sections will thus become greatly distorted in the extruded bar, the middle zone being greatly in advance of the outer zones.

Piercing

As indicated by Fig. 15(a), on piercing, the formation of a slip-line system composed of logarithmic spirals is out of the question, since with this type of stressing the material forced away will not flow off parallel to the axis of the

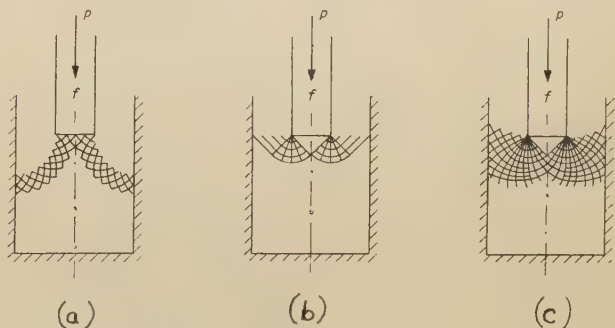


FIG. 15—Slip-line systems on piercing. (a) Logarithmic spirals; (b) straight lines and circles; and (c) straight lines, circles, and spirals

piercer. The conditions are adequately represented, however, by the stress-line system of Fig. 15(b), although the assumption must again be made that the deformation zone extends beyond the limits drawn in the diagram. The material immediately before the piercer will again not take part in the deformation. Finally, owing to the friction between the rising material and the container wall, the angle α will exceed the value of $\pi/2$ by the magnitude of the angle of

friction ρ . Thus the stress conditions actually prevailing are presumably represented best by a slip-layer system of the type reproduced in Fig. 15(c), in which for an area of hole f , the piercing force P has the following value:

$$P = f \cdot k_f \left(1 + \frac{\pi}{2} + \rho \right) \quad (14)$$

In accordance with the above deductions, Siebel and Fangmeier⁶ observed in experiments on the piercing of soft lead that the relative mandrel pressure P/f remained constant between 8.7 and 9.1 kg./sq. mm. over a wide range of conditions.

In order to obtain as clear as possible a picture of the stress conditions, the principal-stress

trajectories on extrusion and piercing corresponding to the slip-line systems of Figs. 14(c) and 15(c) have been represented in Figs. 16 and 17, respectively, the magnitude of the principal stresses at each point of the field of the trajectories having been determined with the aid of the above equations.

As shown by Fig. 16, in extrusion the σ_2 lines are at some distance from the opening of the die are at first approximately circular, whereas the σ_1 trajectories are originally directed radially to the centre of the die, being diverted in the vicinity of the die opening into the direction of the axis of the extruded bar. If internal stresses possibly present are left out of consideration, the compressive stress in the extruded bar is zero, rising in nearly all 'flow tubes' in the same manner until a value twice that of the resistance to deformation k_f is reached, as shown in Fig. 16. In the transverse direction (σ_2 direction) compressive stresses are active, which exceed the σ_1 stresses by the value of the resistance to deformation. Thus the state of stress corresponds roughly to that of a semi-circular arch spread over the opening of the die and stressed by the pressure σ_1 acting in radial direction.

On piercing, the σ_1 trajectories run approximately in circular direction around the front face of the piercer, whilst the σ_2 trajectories radiate from the piercer to the wall of the die. In front of the piercer a compressive stress prevails in the σ_2 direction with a magnitude three times that of the resistance to deformation. This stress decreases along the trajectories a, b , and c , reaching a value of $-k_f$ at the outer wall, whereas the decrease along the trajectories d, e, f , and g is slight. In the σ_1 direction zero stress prevails in the rising metal, merely elastic deformations again being left out of consideration. Along the σ_1 trajectories the compressive stress rises gradually, reaching a value of $-2k_f$ immediately before the piercer.

For an accurate study of the stress conditions it would be necessary to include also the merely elastically stressed regions in the investigation. Only then would it be possible to determine the limits of the plastically stressed region exactly. On the whole, the stress distribution in the regions close to the deformation zone will deviate only slightly from that determined according to Hencky's method. In any case, the above examples indicate that the method of investigation described is perfectly suitable to provide some insight into the stress conditions prevailing in shaping processes carried out in practice. Its application must remain limited to plane deformation processes, however. It must

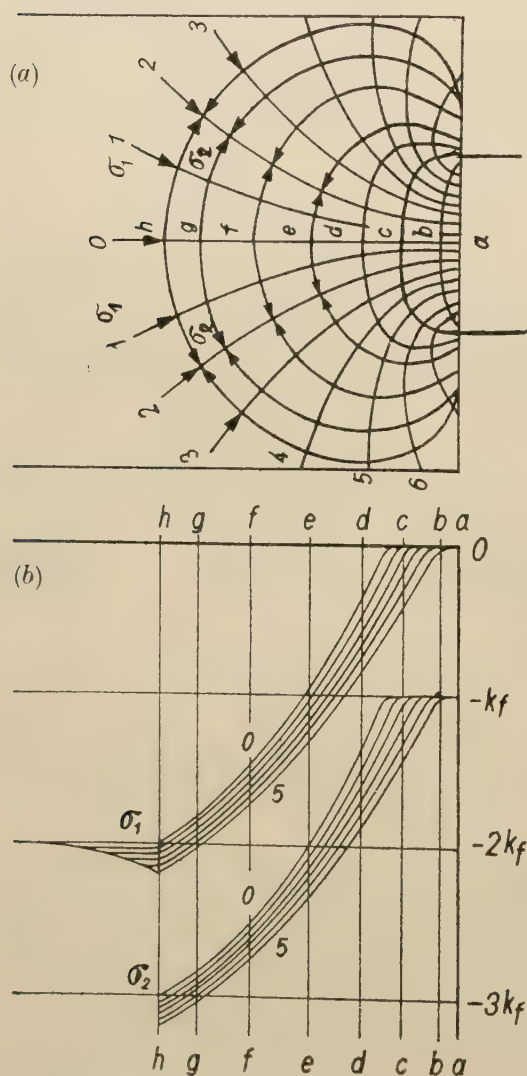


FIG. 16—Stress trajectories and distribution of principal stresses on extrusion

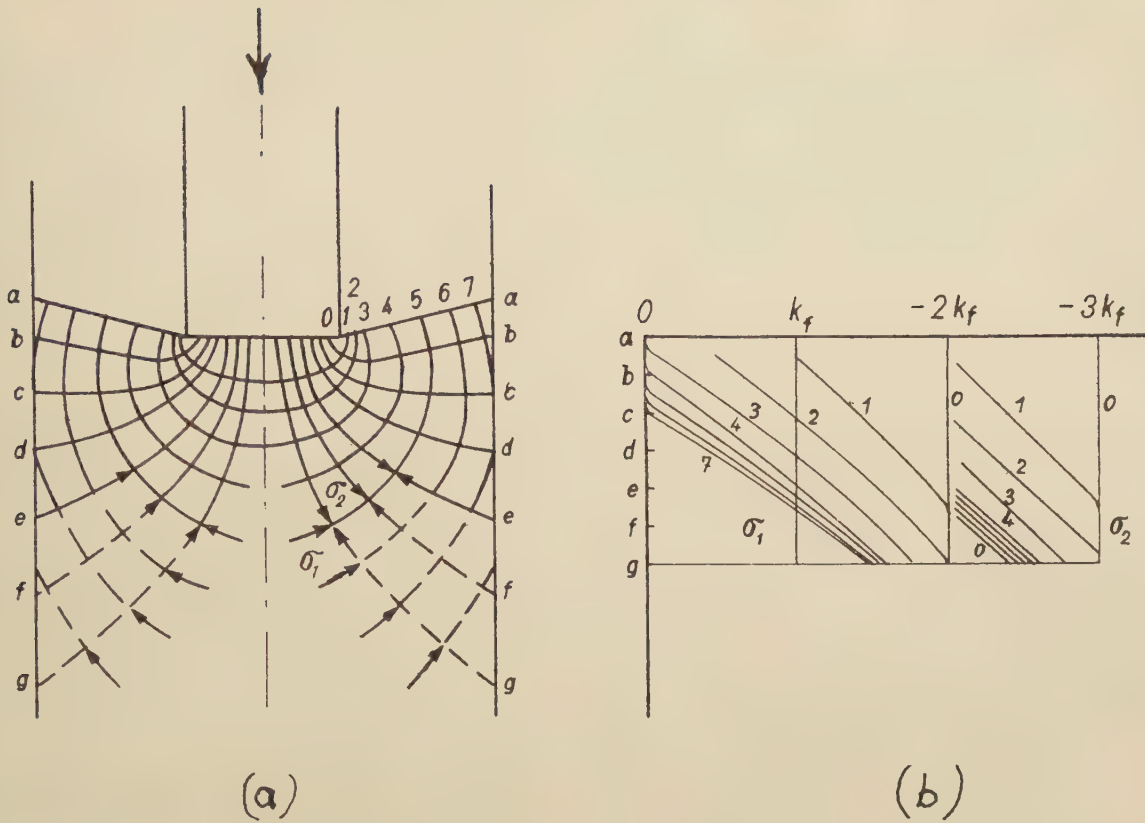


FIG. 17—Stress trajectories and distribution of principal stresses on piercing

further be borne in mind that work-hardening is not taken into account in Hencky's method.

THE EFFECT OF WORK-HARDENING

Where a work-hardening metal is concerned, it is no longer permissible to assume that the shear stress K in the slip layers of the α and β families has the same magnitude throughout, as the shear stress varies along the slip lines in accordance with the state of deformation and work-hardening prevailing at any point of the slip-line system. Based on a consideration of the equilibrium the mean pressure p is then found to be :

$$\begin{aligned} \Delta p_\alpha &= -\int_0^{\Delta\beta} 2K d\beta - \int_0^{\Delta\beta} \frac{\delta K}{\delta\alpha} \frac{\rho_\alpha}{\rho_\beta} d\beta \\ &= -\int_0^{\Delta\beta} k_f \cdot d\beta - \frac{1}{2} \int_0^{\Delta\beta} \frac{\delta k_f}{\delta\alpha} \frac{\rho_\alpha}{\rho_\beta} d\beta \end{aligned} \quad (15)$$

$$\begin{aligned} \Delta p_\beta &= -\int_0^{\Delta\alpha} 2K d\alpha - \int_0^{\Delta\alpha} \frac{\delta K}{\delta\beta} \frac{\rho_\beta}{\rho_\alpha} d\alpha \\ &= -\int_0^{\Delta\alpha} k_f \cdot d\alpha - \frac{1}{2} \int_0^{\Delta\alpha} \frac{\delta k_f}{\delta\beta} \frac{\rho_\beta}{\rho_\alpha} d\alpha \end{aligned} \quad (16)$$

The first terms of equations (15) and (16) represent the product of the mean resistance to deformation and the angles ($\Delta\alpha$ and $\Delta\beta$, respectively) by which the inclination of the slip lines considered varies. The second terms of the equations are governed by the rate of work-hardening in the transverse direction, and the curvatures ρ_α and ρ_β of the α and β slip lines, respectively. With constant K , or k_f , the second terms become zero, reducing the equations to the simple form of equations (1) and (2).

If work-hardening takes place, the slip lines of a family are no longer inclined to each other by a constant angle $d\alpha$ or $d\beta$, but the angles vary in accordance with the following equations :

$$\begin{aligned} \Delta d\alpha &= \frac{\Delta v}{4K\rho_\alpha} \left(\rho_\beta \frac{\delta K}{\delta u} - \rho_\alpha \frac{\delta K}{\delta v} \right) d\alpha \\ &= \frac{\Delta v}{4k_f\rho_\alpha} \left(\rho_\beta \frac{\delta k_f}{\delta u} - \rho_\alpha \frac{\delta k_f}{\delta v} \right) d\alpha \end{aligned} \quad (17)$$

$$\begin{aligned} \Delta d\beta &= \frac{\Delta u}{4K\rho_\beta} \left(\rho_\alpha \frac{\delta K}{\delta v} - \rho_\beta \frac{\delta K}{\delta u} \right) d\beta \\ &= \frac{\Delta u}{4k_f\rho_\beta} \left(\rho_\alpha \frac{\delta k_f}{\delta v} - \rho_\beta \frac{\delta k_f}{\delta u} \right) d\beta \end{aligned} \quad (18)$$

When advancing along a slip line by distances Δu and Δv , the angle which this slip line forms with the neighbouring lines increases and decreases respectively, the variation being proportional to the difference between the products of the mean rate of work-hardening and the radius of curvature in the two directions of slip, and inversely proportional to the product of the mean resistance to deformation and the radius of curvature of the slip line under consideration.

With zero rate of work-hardening the terms in brackets in equations (17) and (18) also become zero, the slip lines of one family being inclined to one another by the same angle throughout, in accordance with the second Hencky law. The angle between the slip lines remains constant even if the same rate of work-hardening prevails in both directions of slip and the slip lines have the same curvature in both directions. The second condition is fulfilled if the slip-line system consists of logarithmic spirals, as is the case in deep-drawing and tube-drawing by the cupping process.

Owing to the rotational symmetry of the flow of the material, work-hardening is the same in both directions of slip in these cases also, so that the second Hencky law is applicable with these kinds of deformation processes also in the case of work-hardening metals. However, even in cases in which the radii of curvature of the two families of slip lines deviate from each other, the variation of the angle between the slip lines is usually slight with normal work-hardening. Slip-line systems traced without consideration of the variation of the angle will thus yield a useful approximate solution even where work-hardening materials are concerned.

SUMMARY

In the case of plane deformation the Hencky laws and the rules deduced by Prandtl regarding the course of slip lines allow, in a simple way, the tracing of slip-line systems in accordance with the equilibrium conditions in the plastic state; and based on the knowledge of the slip-line system it becomes possible to determine the stress distribution in the deformed region. The slip-line systems designed for constant shear stress are applicable also to work-hardening materials if the slip lines possess the same curvature in both directions, and in other cases the

slip-line systems determined in this way will yield an approximate solution.

The method of investigation has been applied to a number of direct compression, cupping, and pressing processes occurring in practice. It was found that Prandtl's theory regarding the resistance to flow on compression between rough plane plates is applicable also in the case in which the shear stress τ at the compressing surfaces possesses a constant value μk_f . In die-forging and cold-rolling, separate slip-layer systems are active at the compressing surfaces on either side of the piece, which systems affect each other as they advance.

In rolling, mainly the slip layers originating at the entering edge are effective, spreading over the whole length of the rolling stock as rolling is continued.

In deep-drawing and in tube-drawing, the slip lines are formed by a system of logarithmic spirals. The same applies in the case of the frictionless drawing of strip. If the friction at the die wall is taken into account the spirals have a greater inclination at the die wall, which results in a more pronounced curvature of the slip lines and a correspondingly greater longitudinal stress with simultaneous decrease of the transverse compressive stress. When using short dies, stress conditions similar to those in die-forging with narrow dies are developed owing to the cohesion of the metal.

In extrusion and piercing, the boundary conditions given are fulfilled best by systems of slip layers which correspond to those prevailing during the advance of a cutting edge into a semi-infinite block, the region of deformation reaching to a certain extent into the original billet. In extrusion the trajectories of the transverse stress are approximately semicircular around the opening of the die, whilst on piercing they run from the front face of the piercer to both sides towards the die wall.

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A New Scheme for the Microchemical Analysis of Ferrous Alloys*

By E. J. Vaughan, M.Sc., F.R.I.C., A.R.C.S., D.I.C.,†
and C. Whalley, B.Sc., A.R.I.C.†

SYNOPSIS

The paper describes the development of accurate microchemical methods of analysis for extremely small samples of steels and other ferrous alloys. Use is made of absorptiometric methods wherever possible to complete the determinations, and chemical separations are reduced to the absolute minimum. Precise conditions for the individual determinations of the elements carbon, silicon, phosphorus, sulphur, manganese, nickel, molybdenum, chromium, vanadium, cobalt, copper, tungsten, titanium, and iron are given in full, and by the application of these methods the analysis of most types of ferrous alloys can be carried out on a sample weight of 80 mg. Many of the individual determinations are fitted together into composite schemes and the most comprehensive of these allows for the determination of all the above-mentioned elements with the exception of carbon, silicon, phosphorus, and sulphur on a single sample weight of 15 mg. These composite schemes of analysis are flexible and can readily be adjusted or simplified according to the nature of the alloy under consideration. Methods of obtaining samples in a satisfactory state of division and cleanliness, and the special small-scale apparatus used for performing the manipulations are described. Full details are given for the construction and operation of a small high-temperature micro-combustion furnace for use in the determination of carbon and sulphur. Typical results of the application of the methods to a wide variety of standard alloys by different analysts are given together with results showing the speed of operation of the methods. Finally, a number of detailed metallurgical problems to which the new technique has been successfully applied are enumerated.

DURING the past decade the application of micro-analytical methods to the examination of ferrous alloys has made considerable progress. The first attempt to apply these methods to the examination of metals was made by Benedicks and Treje,¹ who reviewed qualitative methods for the identification of different types of alloys, and who suggested the possibility of the application of microchemical methods to the examination of inclusions and of element distribution in ferrous alloys. Later, LeRoy² advanced the first quantitative applications of microchemical methods of analysis to the investigation of metals, and detailed quantitative microchemical methods for the determination of manganese, phosphorus, and chromium in steel. Among the conclusions he drew were:

- (a) A micro balance was essential.
- (b) Gravimetric methods as a rule were not sufficiently sensitive.
- (c) Micro-colorimetric and micro-titrimetric methods gave more consistent results and the former type were definitely preferable.

LeRoy carried out his quantitative determinations on sample weights of the order of 5 mg., but the degree of accuracy which he attained was not comparable with the accuracy given by standard chemical methods. In addition to the particular quantitative methods mentioned he suggested numerous applications of microchemical methods to metallurgical problems including the examination of dendritic segregation, the examination of surface oxidation products, and other heterogeneity problems.

This preliminary work was followed by the much more comprehensive investigations of Klinger, Koch, and Blaschczyk,³ who reported on methods for the microchemical determination of most of the common elements appearing in steels and similar alloys. Like LeRoy they found that the most satisfactory method of approaching the problem was by the application of the light

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TABLE I—Interference of Alloying Elements on Established Macro Methods

TABLE I—Interference of Alloying Elements on Established Macro Methods												
Element Under Consideration	Condition for Absorption Measurement	Other Elements Present										
		Manganese	Silicon	Nickel	Chromium	Molybdenum	Vanadium	Tungsten	Cobalt	Copper	Titanium	Tungsten and Vanadium
Manganese	Permanganate	...	No effect	Direct method satisfactory in the presence of 25% of Ni	No effect, direct method satisfactory in the presence of 25% Cr	No effect	No effect	No effect, extra phosphoric acid may be reqd. to keep high tungsten in soln.	No effect if a diff. method is employed for cobalt steels	No effect	No effect	No effect
Silicon	Molybdenum blue	No effect	...	No effect up to 25%	No effect up to 25%	No effect up to 10%	No effect up to 10%	No effect up to 20%	No effect up to 35%	No effect	No effect	No effect
Nickel	Oxidized dimethyl glyoxime salt	No effect	No effect	...	Diff. Method or correction graph. 18% Cr \equiv 0.10% Ni	No effect	No effect	No effect up to 20%	Correction graph 20% Co \equiv 0.09% Ni	Correction graph above 5% Cu	No effect	Diff. method
Chromium	Dichromate	No effect	No effect	Diff. method or correction graph. 25% Ni \equiv 0.13% Cr.	...	No effect	No effect	No effect	Difference method or correction graph 16% Co \equiv 0.12% Cr	No effect	No effect	?
Molybdenum	Thiocyanate	No effect	No effect	No effect up to 25%	No effect	...	No effect	No effect up to 6%	Diff. method or correction graph 20% Co \equiv 0.11% Mo	No effect up to 0.25% filtration necessary up to 3%	No effect	No effect
Vanadium	Pervanadate	No effect	No effect	No effect	Correction graph 1% Mo \equiv 0.026V	...	?	Diff. method or correction graph 20% Co \equiv 0.08% V	No effect	?	?	?

absorption characteristics of coloured solutions, and in practically every method reported the determinations were completed by the use of an absorptiometer. The methods, however, were not ideal in that they often involved complicated separations which led to a considerable decrease in the accuracy of the results obtained, and also were not generally applicable to any type of ferrous alloy. Further, the amount of material taken was still fairly large and for a complete analysis for the elements carbon, silicon, manganese, sulphur, phosphorus, nickel, chromium, molybdenum, and vanadium, a sample weight of the order of 500 mg. was needed to give reasonably accurate results.

During recent years, numerous small metallurgical samples were passed to the chemical laboratory for analysis. These small samples presented a series of difficulties to the analyst because the majority of the elements for which analytical results were required were minor constituents of the alloys and seldom exceeded 1% of the total composition. Furthermore, the samples were usually of unknown types and composition and were often of shapes such as to render possible only a preliminary qualitative examination by means of the spectrochemical technique.

In view of the wide scope of the problems and their importance, it was decided to develop a special technique of microchemical analysis which could be applied to the examination of these very small samples and which would enable a complete analysis to be carried out on a sample weight of not more than 80 mg., irrespective of the composition of the alloy.

Combining the conclusions of LeRoy and Klinger with experience gained at first hand it was decided to endeavour to complete as many of the determinations as possible using the Spekker photo-electric absorptiometer. The work of Vaughan,^{4, 5} had resulted in the presentation of a scheme for the analysis of the principally occurring alloying elements in steels on a macro scale. This scheme of analysis was applicable to most types of plain and alloy steels with the exception of high-speed tool steels, and it was taken as the starting point of the investigation. The first step was to study on the macro scale the applicability of the methods when all of the alloying elements likely to be met with in the widest range of steels were present, and the results obtained are shown in Table 1.

From consideration of this Table it was decided that the methods for manganese, nickel, molybdenum, and silicon, since they were subject to very little interference from other alloying elements

present, were suitable for modification by the application of a micro-analytical technique, whereas the methods for chromium and vanadium were either insufficiently sensitive as judged by the weight of the sample taken, or had too limited an application in the presence of other alloying elements. As the method given by Vaughan⁴ for the determination of phosphorous in steel was also suitable for modification, it followed that new methods were required for the determination of chromium, vanadium, cobalt, titanium, tungsten, iron, sulphur, and carbon in order to achieve the results for which the investigation was initiated.

The original preparatory work which was carried out utilized the standard size 1.0-cm. and 0.5-cm. absorptiometer cells, and just enough of the alloy sample was taken to produce a final volume of solution sufficient to fill these cells in accordance with the established conditions of the macro methods. The results obtained were encouraging but were looked upon purely as a preliminary to the real scheme of analysis. Some idea of the progress made in this preliminary investigation has already been detailed by Vaughan.⁵

A critical examination of the absorptiometer cells was next carried out and it was found that the rays of light from the absorptiometer lens system passed through only a very small volume of the solution present in the cell. The greater part of the solution, therefore, and consequently the greater part of the sample, was not being utilized for the absorption measurement, so it was decided to attempt the design of special micro absorptiometer cells of a maximum capacity of 5.0 ml. and of an optical depth of 3.0 cm. The volume of 5.0 ml. was chosen as being the smallest final volume which was workable with the apparatus at our disposal. These cells were manufactured by Messrs. Tintometer, Ltd., and were used with a special metal adaptor which fitted on to the normal absorptiometer slide. In addition to cells of optical depth 3.0 cm., a range of cells of optical depths 2.0 cm., 1.0 cm., 0.5 cm., and 0.25 cm. were manufactured to fit the adaptor, so that no matter how great the intensity of the coloured complex, it was possible to measure the absorption of the solution without further dilution. In general, the 3.0-cm. cell was the one chosen for the normal working range, so that concentrations of elements up to twelve times the normal (3.0 cm. to 0.25 cm.) could be determined without modification of the conditions of the method, and so made these conditions independent of the element concentration.

The cells and the adaptor are illustrated in

Fig. 1. They were used throughout the investigation, and it would have been impossible to have achieved the results recorded later without them.

PREPARATION OF THE SAMPLE

The samples received, in addition to being very small, were often either in the form of lumps or other awkwardly shaped pieces. In order to obtain results representative of the composition

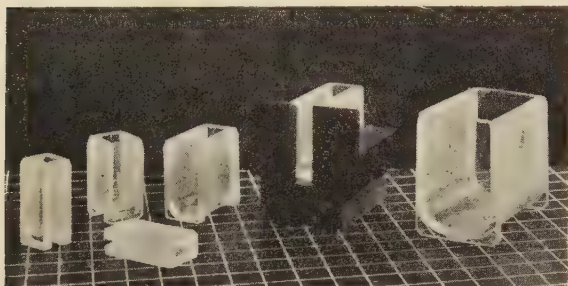


FIG. 1—Micro absorptiometer cells and adaptor compared with 4-cm. normal-sized cell

of the material as a whole it was necessary to prepare the sample in as fine a state of division as its nature rendered possible. One of the following methods of preparation was used, therefore, the choice of method varying according to the precise nature of the sample:

(a) Treated in small milling machine to obtain fine millings.

(b) Turned down on a watchmaker's or small model-maker's lathe in order to obtain very fine turnings.

(c) Subjected to drilling, using a very small drill. (This method was employed for the examination of surface-area variations, inclusions, and segregate analysis.)

(d) Flattened in a hardened steel mortar and cut into very small pieces (annealing in an inert atmosphere to soften the material was first carried out if necessary).

After the sample had been obtained in as fine a state of division as possible by the most suitable of the above processes, it was necessary to free it from any extraneous or deleterious matter which might have been picked up during the preparation. Large impurities were removed by subjecting the sample to treatment with a magnet, and in difficult cases by sorting with fine forceps under a microscope with a low-power lens. The prepared sample was then carefully washed twice with pure ether to remove grease and oil, and then dried in the hot-air oven and stored in specially made small sample tubes.

THE APPARATUS USED

For weighing the very small amounts of sample an Oertling microchemical balance was used.

The balance was placed against an outside wall on a secure and firm table so that any vibration effect was eliminated or cut down to an absolute minimum. The normal precautions involving the use of the microchemical balance as laid down by Emich⁶ and by Pregl⁷ were taken as far as was practicable. As receptacles for weighing-out the samples, weighing bottles of the 'tobacco pipe' type were used, and both they and the sample were not touched by hand but were handled with sharp pointed forceps. Often, small particles of the sample tended to adhere to the glass of the weighing bottle and were removed by using a snipe's feather mounted in a thin glass rod as a brush. In the case of powders which adhered badly to the glass, 'spike' type weighing bottles with hollow ends were preferred, since they could easily be washed out after completing the weighing. In every case a counter-balance of a similar type of bottle was always used on the right-hand pan of the balance.

For carrying out the experimental- and chemical-preparation work on the weighed sample, special small glass apparatus made from Pyrex or Hysil heat-resisting glass was used. The small 10-ml. conical-type flask with a fairly wide mouth was found to be ideal for the majority of the experimental work carried out, but for larger volumes of solution 25-ml. conical flasks were used, and where very small volumes of solutions were to be treated without danger of evaporation to dryness a tall-type 5-ml. beaker with a relatively narrow base was found necessary.

Fractionation of the stock solution of the sample was carried out by the use of Pregl-type micro pipettes with capacities of 2.0 ml., 1.0 ml., 0.5 ml., and 0.1 ml., and these pipettes were also used for the accurate measurement of the added volumes of reagents when this was necessary. Where extreme accuracy was not required small graduated dropping-type pipettes with capacities of 1.0 ml., 0.5 ml., and 0.1 ml. were used.

Since the determinations were to be completed using the absorptiometer wherever possible, the provision of an accurate method of obtaining a final standard volume of solution was very necessary. The usual type of standard volumetric flask was found to be quite suitable for volumes of 10.0 ml. and over, and flasks of this type with capacities of 25.0 ml., 20.0 ml., 15.0 ml., and 10.0 ml. were used whenever the experimental work required them. In the majority of the determinations, however, a final volume of 5.0 ml., the capacity of the special 3.0-cm. micro absorptiometer cell, was envisaged, and flasks of the standard volumetric

type of 5.0 ml. capacity were found to be unsuitable for use owing to the difficulties experienced in mixing the solutions and to the frequent air locks arising in the narrow neck. To overcome these difficulties an apparatus was devised in these laboratories, to enable a final volume of solution to be accurately diluted to 5.0 ml.

The device adopted is shown in Fig. 2, and whilst far from ideal it minimized the above-mentioned difficulties quite considerably. The apparatus is made from a standard Pyrex ground-glass joint of size 00 and consists of a 10.0-ml. capacity boiling flask and a 5.0-ml. capacity graduated bulb joined by means of a tapered ground-glass joint ground down to a knife edge. In use the alloy solution is transferred to the boiling flask by washing with a fine micro wash-bottle, and the various reagents necessary for the production of the coloured complex are added; the graduated bulb is then placed on top and the whole apparatus is inverted. After allowing time for drainage, the boiling flask is

used whenever the final volume of the solution could not be controlled by the addition of measured volumes of solutions of reagents, and in the chemical procedure described later it is utilized whenever instructions indicate that dilution to a volume of 5.0 ml. is necessary.

When methods involving separation and filtration were found necessary, the filter-stick technique devised by Emich⁶ was utilized, and either porcelain or platinum filter sticks

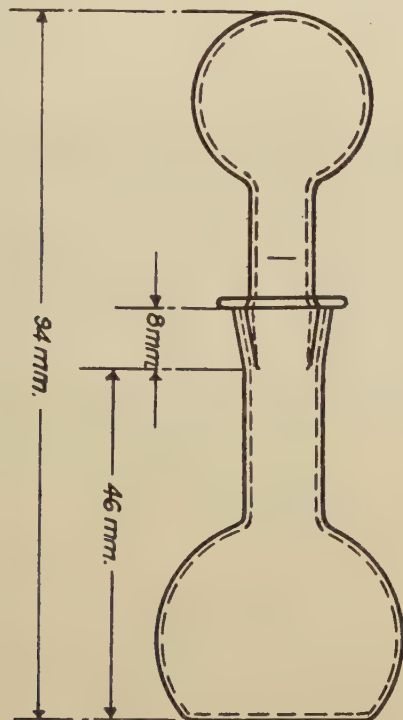


FIG. 2—Apparatus for the dilution of solutions to a standard volume of 5 ml.

removed and the volume of liquid is adjusted to the graduation mark using the micro wash-bottle. The boiling flask is then replaced and the apparatus is inverted several times in order to obtain complete mixing. The solution is then transferred to the absorptiometer cell for measurement on the instrument. This apparatus was



FIG. 3—Micro filtration apparatus, pipettes, beakers, and volumetric flasks

were used in conjunction with the apparatus shown in Fig. 3, which also shows a representative assortment of the small-type glass apparatus. These methods of filtration did not involve any actual transference of the precipitate and rendered possible the accurate determination of elements such as copper even after a separation had been made. For the analysis of cast iron, where the removal of silica and graphite is necessary before absorption measurement, filtration was carried out by the use of small asbestos pads contained in an Emich glass filter stick.

For certain determinations such as carbon and sulphur, special apparatus was required which will be described in detail under the appropriate heading.

DETERMINATION OF INDIVIDUAL ELEMENTS

Separate methods for the determination of each element have been developed and as far as possible these were made specific, but where this could not be realized either the 'difference' technique or the 'correction curve' technique was applied. In all cases, however, it was found necessary to carry through a control blank on either pure iron or on the reagents used, in order to allow for errors arising from impurities in the reagents or from differences in the absorption cells.

Table II gives a summary of the methods, the reagents employed and the sample weights used, and the full experimental details for each determination on a separate sample weight.

Microchemical Determination of Silicon in Ferrous Alloys

The method depends upon the formation of molybdenum blue by the reduction of ammonium silico-molybdate with stannous chloride and is a straightforward application of the macro method

TABLE II—*Review of Methods*

Element	Reaction Employed	Weight of Sample, mg.	Range of Method, %
Carbon	Gravimetric CO ₂	50.0	0.3-0
Sulphur (I)	Titration of SO ₂ with iodine	50.0	0.0-0.3
do. (II)	Diphenylcarbazide	10.0	0.0-0.15
Silicon	Molybdenum blue complex	1.0	0.6-0
Phosphorus	Molybdenum blue complex	5.0	0.1-0
Manganese	Permanganate	4.0	0.12-0
Nickel	Oxidized dimethylglyoxime complex	0.4	0.30-0
Chromium (I)	Caustic soda separation	0.8	0.6-0
do. (II)	Direct diphenylcarbazide complex	0.5	0.6-0
do. (III)	Dichromate	4.0	0.30-0
Molybdenum	Thiocyanate	1.6	0.9-0
Vanadium (I)	Separation, Strychnine finish	5.0	0.3-0
do. (II)	Diphenylamine complex	1.0	0.4-0
Copper (I)	Direct diethyldithiocarbamate complex	4.0	0.3-0
do. (II)	Separation, diethyldithiocarbamate complex	4.0	0.6-0
Cobalt (I)	Nitroso-R-salt complex	1.0	0.6-0
do. (II)	do. do.	0.5	0.20-0
Tungsten	Dithiol complex	2.0	0.5-0
Titanium (I)	Direct thymol complex	2.0	0.4-0
do. (II)	Separation, thymol complex	2.0	0.4-0
Iron	Citrate	2.0	0.100-0

of Vaughan,⁵ the quantities of sample and reagents used being suitably modified. The silico-molybdate complex is produced by the addition of ammonium molybdate solution to a solution of the alloy in weak sulphuric acid. A very low acid concentration is necessary at this stage in order to form the complex silico-molybdate, but this also allows the formation of complex phospho-, vanado-, and arseno-molybdates. The interference by reduction to molybdenum blue of complex molybdates in solution other than silico-molybdate, and of the excess ammonium molybdate, is prevented by increasing the acidity of the solution to greater than 1.5 *N* after the formation of the molybdates and before their reduction with stannous chloride.

None of the elements commonly met with in ferrous alloys interfere with the method. Tungsten, if present, must be removed by filtration using the filter-stick technique before the production of the complex molybdates.

Procedure

Dissolve 1.0 mg. of sample in 0.5 ml. of 1:60 sulphuric acid (by volume) in a 5-ml. capacity tall beaker, taking care to avoid low bulk. Oxidize the solution with 0.1 ml. of freshly prepared 1% potassium permanganate solution. Simmer for a few minutes and then reduce the excess permanganate with drops of saturated sulphurous acid solution; boil off the excess, and cool. Add 2.0 ml. of distilled water, 0.5 ml. of 2.5% ammonium molybdate solution, and stand for 5 min. Add 1.0 ml. of 1:2.5 sulphuric acid (by volume) and 0.5 ml. of 0.5% stannous chloride solution in 0.6% hydrochloric acid. Dilute to 5.0 ml. and allow to stand for 10 min.

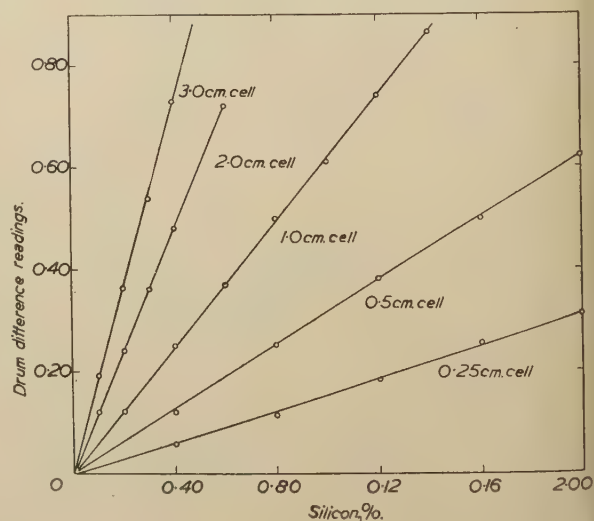


FIG. 4—Graph for the microchemical determination of silicon in ferrous alloys (see Table V)

Measure the absorption of the solution in an appropriate micro cell using Ilford 606 and H503 filters, setting the Spekker at water-to-water 20.

Measure the absorption in the same cell of an equal quantity of Hilger electrolytic iron similarly treated as a blank, and relate the difference reading obtained to a prepared calibration curve.

Details of the scope and accuracy of the method are:

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-0.5	± 0.01
2.0	0.0-0.8	± 0.01
1.0	0.0-1.6	± 0.02
0.5	0.0-3.2	± 0.05
0.25	0.0-6.5	± 0.10

Figure 4 shows the calibration curves prepared by making known additions of a standard solution of sodium silicate to Hilger electrolytic iron and treating as described.

Microchemical Determination of Phosphorus in Ferrous Alloys

The method depends upon the formation of molybdenum blue by the reduction of ammonium molybdate with stannous chloride, and is a modification of the macro method by Vaughan⁴ with a slight variation in the final acid concentration. The acid concentration of the solution throughout the formation of the complex molybdates is such that silico-molybdates are not formed, and the acid concentration at which the reduction is carried out is sufficiently high to prevent the reduction of excess ammonium molybdate and of vanado-molybdates. The interference of arsenic in the method is prevented by fuming with hydrobromic acid before the formation of the molybdates.

The method can be applied only to alloys which are soluble in nitro-sulphuric acid mixtures and hence requires modification for alloys high in chromium.

Tungsten, if present in quantity, must be removed by filtration using the filter-stick technique before the formation of ammonium molybdate.

Procedure.

Dissolve 5.0 mg. of sample in 0.5 ml. of solvent acid (sulphuric acid, (sp. gr. 1.84) 20 ml., nitric acid (sp. gr. 1.42) 10 ml., distilled water 10 ml.) in a 5-ml. capacity tall beaker. Oxidize the solution with 0.2 ml. of 0.5% potassium permanganate solution and simmer. Reduce the excess permanganate with drops of saturated phosphorous acid solution and evaporate to the first appearance of sulphur trioxide fumes.

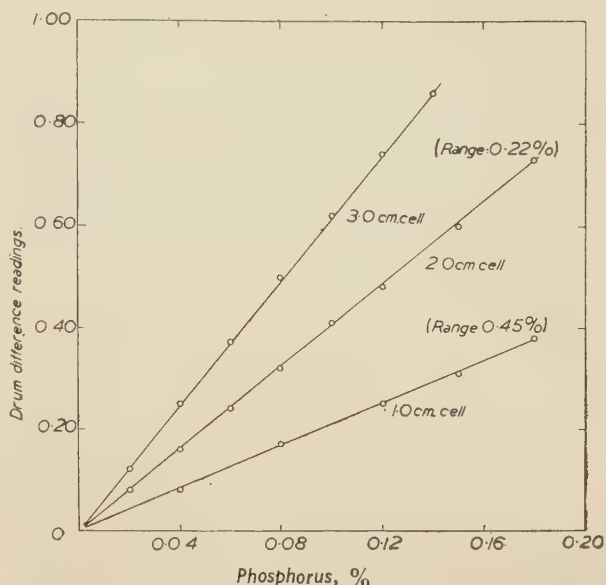


FIG. 5—Graph for the microchemical determination of phosphorus in ferrous alloys (see Table V)

Cool, add 0.5 ml. of distilled water and 0.05 ml. of 50% hydrobromic acid, and evaporate once more to fumes of sulphur trioxide. Cool, add 1.0 ml. of distilled water, gently warm to dissolve the solids, and then cool again. Add in the following order, 2.0 ml. of distilled water, 0.5 ml. of 5% sulphuric acid, 0.5 ml. of 5% ammonium molybdate solution, and 0.5 ml. of 1.5% stannous chloride solution in 2.5% hydrochloric acid, mixing thoroughly after each addition. Dilute to 5.0 ml. and allow to stand for 15 min.

Measure the absorption of the solution in an appropriate micro cell using Ilford 606 and H503 filters, setting the Spekker at water-to-water 1.20.

Measure the absorption in the same cell of an equal quantity of Hilger electrolytic iron similarly treated as a blank, and relate the difference reading obtained to a prepared calibration curve. A correction of 0.003% must be applied for each 10% of chromium present.

For alloys high in chromium, dissolve the sample in 0.5 ml. of aqua regia before adding the solvent acid. Then proceed as above.

Details of the scope and accuracy of the method are:

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-0.14	± 0.003
2.0	0.0-0.22	± 0.005
1.0	0.0-0.45	± 0.010
0.5	0.0-0.90	± 0.020

Figure 5 shows the calibration curves prepared by making known additions of a standard solution of phosphoric acid to Hilger electrolytic iron, and treating as described.

Microchemical Determination of Manganese in Ferrous Alloys

The method depends upon the formation of the permanganate ion by the oxidation of the manganese ion. The macro method of Vaughan⁴ used ammonium persulphate and silver nitrate as oxidizing agents, and whilst these reagents were found to be quite satisfactory on the micro scale, in order to allow for further determinations

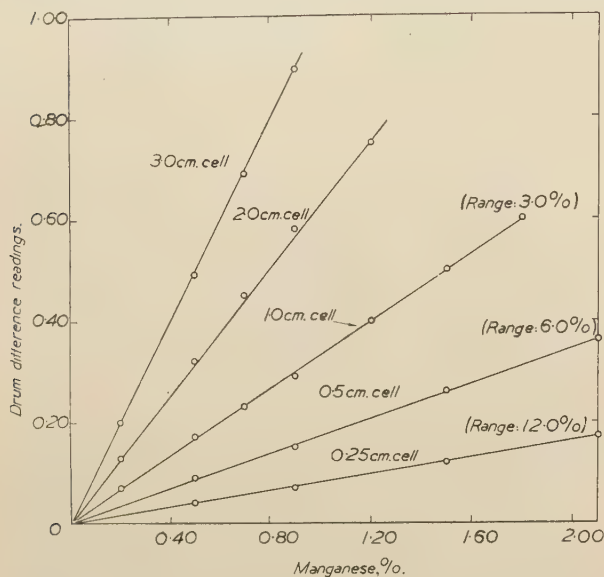


FIG. 6—Graph for the microchemical determination of manganese in ferrous alloys (see Table V)

to be made on the solution the presence of silver salts was undesirable. Therefore, use was made of potassium periodate as the oxidizing agent for the manganese. Chromium, if present, is partially converted to dichromate, allowance for the absorption of which is made by measuring the absorption of the solution after the preferential reduction of the manganese with sodium nitrite solution. Cobalt, if present, also gives rise to a small absorption which is determined in a similar manner.

Procedure

Dissolve 4.0 mg. of sample in 0.5 ml. of 50% 'Spekker acid' (sulphuric acid (sp. gr. 1.84) 15 ml., phosphoric acid (sp. gr. 1.75) 15 ml., distilled water 70 ml.) in a 10-ml. conical flask. Add 1 drop of nitric acid (sp. gr. 1.42) and evaporate to fumes of sulphur trioxide. Cool, add 2.0 ml. of 0.6% potassium periodate solution, and simmer to a volume of about 1.0 ml. Cool, add 0.05 ml. of 10% urea solution, and dilute to 5.0 ml.

Measure the absorption of the solution in an appropriate micro cell using Wratten 74 and

H503 filters, setting the Spekker at water-to-water 1.20.

Add 0.05 ml. of 2% sodium nitrite solution, shake, and again measure the absorption in the same cell as a blank. Relate the difference reading obtained to a prepared calibration curve.

Details of the scope and accuracy of the method are:

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-1.0	±0.01
2.0	0.0-1.5	±0.02
1.0	0.0-3.0	±0.04
0.5	0.0-6.0	±0.08
0.25	0.0-12.0	±0.16

Figure 6 shows the calibration curves prepared by adding amounts of a standard solution of potassium permanganate to Hilger electrolytic iron and treating as described.

Microchemical Determination of Molybdenum in Ferrous Alloys

The method depends upon the formation of a complex molybdenum thiocyanate by the action of sodium thiocyanate solution on reduced molybdenum. Iron yields intensely coloured ferric thiocyanate which is removed by reduction with stannous chloride, and the molybdenum thiocyanate complex is stabilized for at least 2 hr. by the use of sulphuric and perchloric acids.

The only interfering element is copper which in amounts greater than 1% produces a precipitate of cuprous thiocyanate. If the copper content is not greater than 5%, filtration of the coloured solution using the filter-stick technique overcomes the difficulty. Chromium in large amounts gives rise to a small additive absorption, allowance for which is made by simple correction.

Procedure

Dissolve 1.6 mg. of sample in 0.5 ml. of 20% Spekker acid in a 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr. 1.42) and evaporate to fumes of sulphur trioxide. Cool, add 2.0 ml. of distilled water, 0.5 ml. of 1:2 perchloric acid (sp. gr. 1.54), 1.0 ml. of 1:1.6 sulphuric acid, 0.5 ml. of 12% sodium thiocyanate solution, and 1.0 ml. of 10% stannous chloride solution in 5% hydrochloric acid. Mix well after each addition and allow to stand for 10 min.

Measure the absorption of the solution in an appropriate micro cell using Ilford 603 and H503 filters, setting the Spekker at water-to-water 0.80.

Measure the absorption in the same cell of all the reagents similarly treated as a blank and relate the difference reading obtained to a prepared calibration curve. A correction of 0.01% must be applied for each 10% of chromium present.

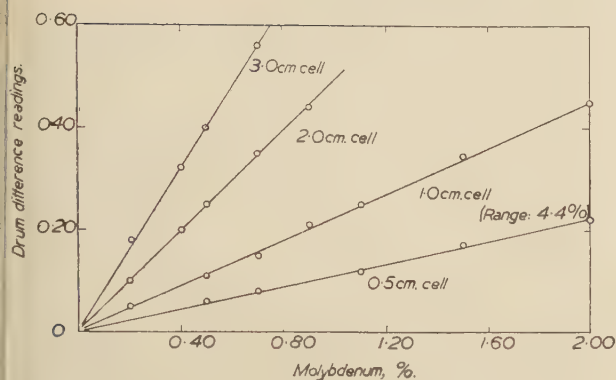


FIG. 7—Graph for the microchemical determination of molybdenum in ferrous alloys (see Table V)

Details of the scope and accuracy of the method are :

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0–0.7	±0.02
2.0	0.0–1.1	±0.03
1.0	0.0–2.2	±0.06
0.5	0.0–4.5	±0.10
0.25	0.0–9.0	±0.20

Figure 7 shows the calibration curves prepared by making known additions of a standard solution of ammonium molybdate to Hilger electrolytic iron and treating as described.

Microchemical Determination of Nickel in Ferrous Alloys

The method depends upon the formation of the oxidized dimethylglyoxime complex in ammoniacal solution and is a modification of the macro method of Vaughan.⁵ The oxidation is carried out by means of a standard solution of iodine, and the dimethylglyoxime reagent is dissolved in 50% ammonium hydroxide as the presence of alcohol is undesirable since it causes fading of the colour and ultimate precipitation. Correction factors must be applied for large amounts of chromium, cobalt, and copper.

Procedure

Dissolve 0.4 mg. of sample in 0.5 ml. of 5% Spekker acid in a 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr. 1.20) and evaporate to fumes of sulphur trioxide. Cool, add 1.0 ml. of 25% ammonium citrate solution, 0.5 ml. of *N*/40 iodine solution, 2.5 ml. of distilled water, and 1.0 ml. of 0.1% dimethylglyoxime solution in 50% ammonium hydroxide, mixing well after each addition.

Measure the absorption of the solution in an appropriate micro cell using Wratten 74 and H503 filters, setting the Spekker at water-to-water 1.20.

Measure the absorption in the same cell of an equal quantity of Hilger electrolytic iron similarly

treated as a blank and relate the difference reading obtained to a prepared calibration curve. A correction of 0.02% for each 10% of chromium present, 0.03% for each 5% of cobalt present, and 0.02% for each 2% of copper present must be applied.

Details of the scope and accuracy are :

Micro Cell Size cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0–4.0	±0.05
2.0	0.0–6.0	±0.08
1.0	0.0–13.0	±0.15
0.5	0.0–26.0	±0.30

Figure 8 shows the calibration curves prepared by adding known amounts of a standard solution of pure nickel to Hilger electrolytic iron and treating as described.

Microchemical Determination of Chromium in Ferrous Alloys

According to the chromium content of the material under consideration one of the following methods can be applied.

Method I (Chromium Content not exceeding 6%)

The method depends upon the formation of the oxidation product of diphenylcarbazide with dichromate in acid solution, and is a straightforward modification of the macro method of Vaughan.⁵ The interference of iron is prevented by its precipitation with sodium hydroxide, and the addition of hydrogen peroxide in alkaline solution ensures the complete oxidation of chromium to chromate. The excess peroxide is removed by boiling and the filter-stick technique is utilized for the separation of the chromate solution from the ferric hydroxide precipitate. No washing

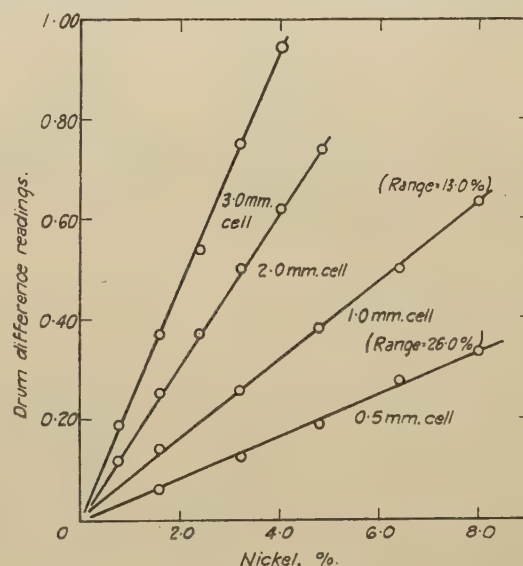


FIG. 8—Graph for the microchemical determination of nickel in ferrous alloys (see Table V)

of the slimy precipitate is necessary since only sufficient solution for an aliquot portion need be filtered. Vanadium in amounts greater than 1% interferes with the method, and molybdenum above 2% gives rise to a small additive absorption, allowance for which must be made by applying a small correction.

Procedure—Dissolve 0.8 mg. of sample in 0.5 ml. of 10% Spekker acid in a wide-mouthed 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr. 1.42) and evaporate to fumes of sulphur trioxide. Cool, add 0.5 ml. of 1% potassium permanganate solution introducing a sealed capillary tube to ensure even boiling, and simmer. Add 1.0 ml. of 15% sodium hydroxide solution and 1.0 ml. of '10 volume' hydrogen peroxide solution. Simmer to remove excess peroxide, cool, and dilute to 5.0 ml.

Allow the precipitate to settle and filter through a porcelain filter stick. Pipette 2.0 ml. of the filtrate into a 10-ml. conical flask, add 2.0 ml. of 5% sulphuric acid and 1.0 ml. of freshly prepared 0.25% diphenylcarbazide solution in 25% alcohol.

Measure the absorption of the solution in an appropriate micro cell using Wratten 74 and H503 filters, setting the Spekker at water-to-water 1:20.

Measure the absorption in the same cell of an equal quantity of Hilger electrolytic iron similarly treated as a blank and relate the difference reading obtained to a prepared calibration curve. A correction of 0.02% for each 2% of molybdenum present must be applied.

Details of the range and accuracy are:

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure %
3.0	0.0-1.0	± 0.03
2.0	0.0-1.5	± 0.05
1.0	0.0-3.0	± 0.10
0.5	0.0-6.0	± 0.20

Figure 9 shows the calibration curves produced by adding known amounts of a standard solution of potassium dichromate to Hilger electrolytic iron and treating as described.

Method II (Chromium Content not exceeding 6%—Direct Method)

This method depends upon the formation of the same colour complex as in Method I but no preliminary separation of the iron is carried out. It was discovered that the addition of phosphoric acid suppressed the oxidizing potential of ferric iron on the diphenylcarbazide reagent. Thus if the addition of phosphoric acid is made after oxidation of the chromium to dichromate by means of silver nitrate and ammonium persulphate the colour can be directly measured without

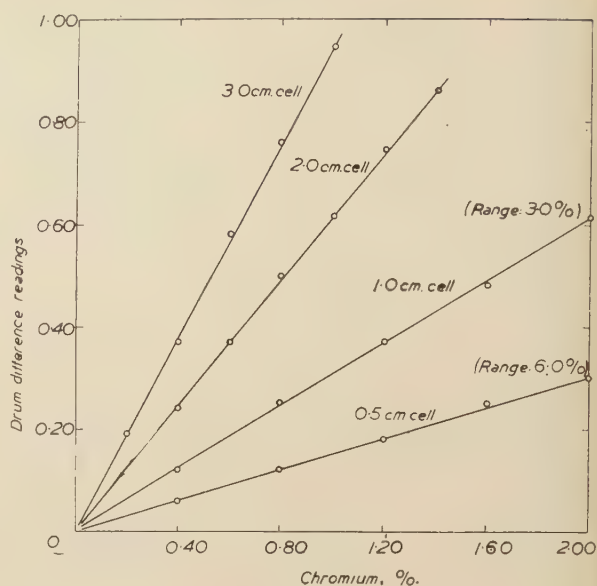


FIG. 9—Graph for the microchemical determination of chromium in ferrous alloys (separation method) (see Table V)

any interference from iron. Complete removal of the ammonium persulphate is ensured by prolonged simmering to prevent the colours being unstable, and the permanganate colour produced at the same time is destroyed by a dilute solution of sodium nitrite followed by urea. Vanadium and molybdenum still interfere as described in Method I.

Procedure—Dissolve 0.5 mg. of sample in 0.5 ml. of 25% Spekker acid in a 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr.

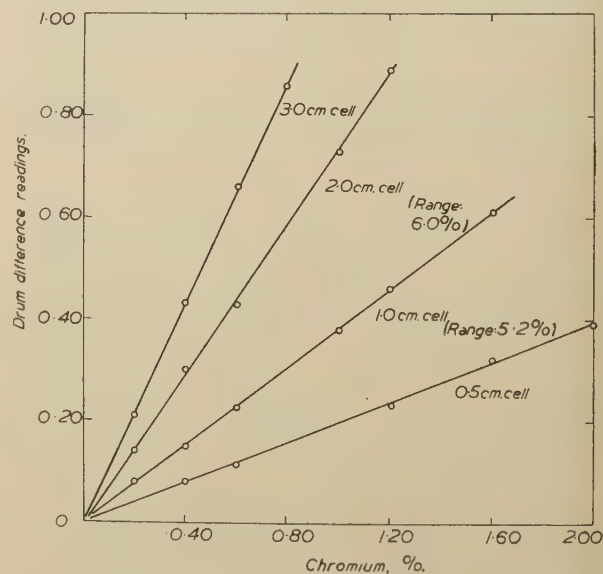


FIG. 10—Graph for the microchemical determination of chromium in ferrous alloys (direct method) (see Table V)

20) and evaporate to fumes of sulphur trioxide. Cool, add 0.5 ml. of 0.15% silver nitrate solution and 0.5 ml. of 1.5% ammonium persulphate solution, and simmer gently for 15 min. Cool, add 1.0 ml. of 25% phosphoric acid, 1.0 ml. of 10% urea solution, and 0.10 ml. of 0.2% sodium nitrite solution. Dilute to 5.0 ml., and add 0.5 ml. of 0.25% diphenylcarbazide solution in 25% alcohol. If the solution is turbid filter through a porcelain filter stick.

Measure the absorption of the solution and the blank as described in Method I and relate the difference reading obtained to a prepared calibration curve. A correction of 0.02% for each 2% of molybdenum present must be applied.

Details of the scope and accuracy are :

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-0.9	± 0.02
2.0	0.0-1.2	± 0.03
1.0	0.0-2.6	± 0.05
0.5	0.0-5.2	± 0.10

Figure 10 shows the calibration curves produced.

Method III (Chromium Content greater than 6%)

This method is applicable to alloys of high chromium content such as stainless- or heat-resisting-type steels and depends upon the formation of dichromate by oxidation of the chromium. The method is consequently subject to all the disadvantages of the corresponding macro method as described in the discussion of the preliminary investigations.

The chromium is oxidized to dichromate by the use of silver nitrate and ammonium persulphate, and the manganese colour is removed by reduction with sodium nitrite. Tungsten and vanadium if present together vitiate this method.

Procedure—Dissolve 4.0 mg. of sample in 0.5 ml. of 50% Spekker acid. Oxidize with 1 drop of nitric acid (sp. gr. 1.42) and evaporate to fumes of sulphur trioxide. Cool, add 1.0 ml. of 0.3% silver nitrate solution and 1.0 ml. of 2.5% ammonium persulphate solution, and simmer for 10 min. Cool, add 0.2 ml. of 10% urea solution and 0.05 ml. of 2% sodium nitrite solution, mix well, and dilute to 5.0 ml.

Measure the absorption of the solution and blank as described in Method I, but using Ilford 601 and H503 filters, and relate the difference reading obtained to a prepared calibration curve. A correction of 0.10% for each 5% of nickel present must be applied.

Details of the scope and accuracy are :

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-9.0	± 0.10
2.0	0.0-15.0	± 0.15
1.0	0.0-30.0	± 0.30
0.5	0.0-60.0	± 0.60

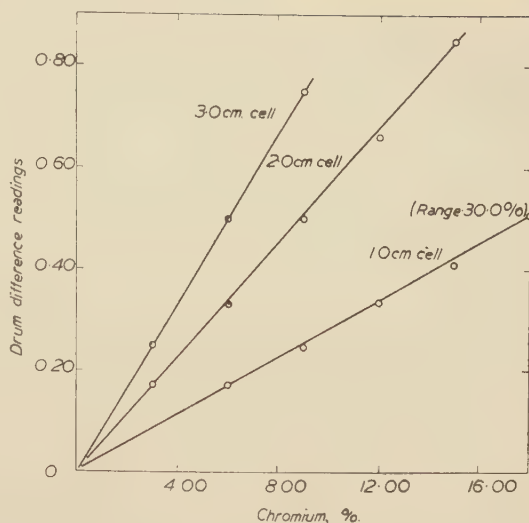


FIG. 11—Graph for the microchemical determination of chromium in high chromium content ferrous alloys (see Table V)

Figure 11 shows the calibration curves produced by adding known amounts of a standard solution of potassium dichromate to Hilger electrolytic iron and treating as described.

Microchemical Determination of Vanadium in Ferrous Alloys

Two methods have been developed for vanadium, one of which is applicable to all types of ferrous alloys and the other to all types except alloys high in tungsten.

Method I

The method depends upon the formation of the complex given by vanadium with strychnine⁸ and is modified from that given by Vaughan.⁵ The vanadium is co-precipitated with phosphorus as complex molybdates and the precipitate is freed from iron by filtration using the filter-stick technique. The precipitate is dissolved in sulphuric acid; the solution is then concentrated and the vanadium is oxidized with potassium chlorate. A violet-coloured complex is produced with a solution of strychnine in concentrated sulphuric acid, which is unstable, but the addition of a drop of nitric acid gives rise to a stable brown-coloured solution the absorption of which is proportional to the vanadium content. The method is applicable to all types of ferrous alloys soluble in nitric acid or aqua regia, and no interference is found from other elements.

Procedure—Dissolve 5.0 mg. of sample in 2.5 ml. of 20% nitric acid in a 10-ml. wide-mouthed conical flask. Add 0.1 ml. of 2.5% sodium phosphate solution, and boil. Cool, add 1.0 ml. of 50% ammonium hydroxide solution

and 2.0 ml. of 5% ammonium molybdate solution. Shake, and stand for a few minutes to allow the precipitate to settle. Filter through a porcelain filter stick, washing the precipitate with 2% nitric acid and finally with distilled water, rejecting the filtrate and washings. Add 2.0 ml. of 50% sulphuric acid to the flask and stick, and warm to dissolve the precipitate. Wash and remove the stick, and evaporate the solution to fumes of sulphur trioxide. Cool, add 2.5 ml. of sulphuric acid (sp. gr. 1.84), one crystal of potassium chlorate, and reflux. Cool, add 1.0 ml. of 0.4% strychnine solution in sulphuric acid (sp. gr. 1.84), and when the violet colour appears fully developed add 0.05 ml. of nitric acid (sp. gr. 1.42) and stand for 15 min.

Measure the absorption of the solution in an appropriate micro cell using Ilford 603 and H503 filters, setting the Spekker at water-to-water 0.80.

Measure the absorption in the same cell of an equal quantity of Hilger electrolytic iron similarly treated as a blank, and relate the difference reading to a prepared calibration curve.

Should treatment with aqua regia be necessary to obtain complete solution of the alloy, evaporate to dryness and redissolve in 2.5 ml. of 20% nitric acid; then proceed as above.

Details of the scope and accuracy are :

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-0.35	± 0.01
2.0	0.0-0.45	± 0.02
1.0	0.0-0.9	± 0.04
0.5	0.0-1.8	± 0.08

and the calibration curves are shown in Fig. 12.

Method II

The method depends upon the formation of the oxidation product of diphenylamine with quinquivalent or septavalent vanadium oxide.⁹ The vanadium is transferred to the higher state of oxidation by treatment with hydrogen peroxide, and the interference of ferric iron is prevented by the addition of strong phosphoric acid to lower the oxidation potential. The treatment with hydrogen peroxide in acid solution also serves to reduce any higher oxidized salts of manganese and chromium which may be present. The excess hydrogen peroxide must be removed by simmering, since all active oxidizing agents must be absent. The method is not applicable if the tungsten content of the alloy exceeds 5%.

Procedure—Dissolve 1.0 mg. of sample in 0.5 ml. of 12.5% Spekker acid in a 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr. 1.42) and evaporate to fumes of sulphur trioxide. Cool, add 1.0 ml. of distilled water and 0.10 ml.

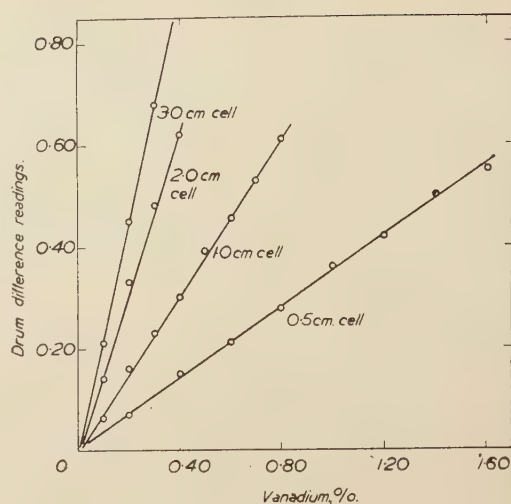


FIG. 12—Graph for the microchemical determination of vanadium in ferrous alloys (separation method) (see Table V)

of '10 volume' hydrogen peroxide. Simmer gently for 15 min. to destroy excess peroxide. Cool, add 1.0 ml. of 50% sulphuric acid, 2.0 ml. of 50% phosphoric acid, and 0.5 ml. of distilled water. Mix well and then add 0.5 ml. of a saturated diphenylamine solution in water (0.2 gm. dissolved in 100 ml. of hot water and filtered), stand for 10 min., and dilute to 5.0 ml.

Measure the absorption of the solution and blank as described in Method I but using Ilford 606 and H503 filters and a 1.20 setting, and relate the difference reading obtained to a prepared calibration curve.

Details of the scope and accuracy are :

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-0.9	± 0.02
2.0	0.0-1.20	± 0.03
1.0	0.0-2.40	± 0.06
0.5	0.0-4.50	± 0.15
0.25	0.0-9.0	± 0.30

and the calibration curves are shown in Fig. 13.

Microchemical Determination of Cobalt in Ferrous Alloys

According to the cobalt content of the material under consideration one of the following methods can be applied.

Method I (Cobalt Content less than 7%)

The method depends upon the formation of the complex of cobalt and nitroso-R-salt, and is a micro adaptation of the routine macro method of Haywood and Wood.¹⁰

Interference from other elements is prevented by forming the coloured complex in a solution buffered with sodium acetate and then adding nitric acid and boiling. The use of Wratten 74

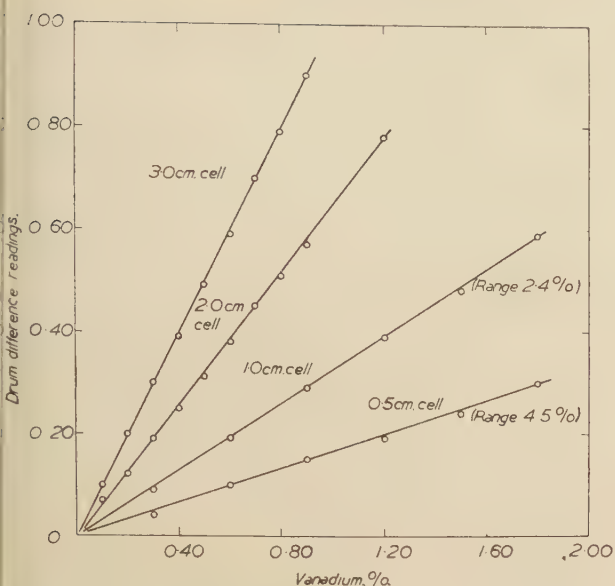


FIG. 13—Graph for the microchemical determination of vanadium in ferrous alloys (direct method) (see Table V)

filters for the absorption measurements eliminates the high blank reading which the original authors recorded.

Procedure—Dissolve 1.0 mg. of sample in 0.5 ml. of 12.5% Spekker acid in a 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr. 1.20) and evaporate to fumes of sulphur

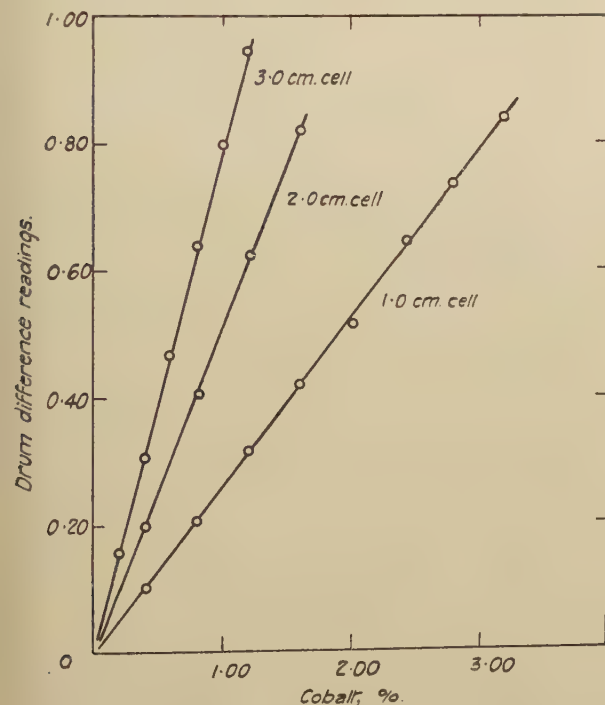


FIG. 14—Graph for the microchemical determination of cobalt in low cobalt content ferrous alloys (see Table V)

trioxide. Cool, add 1.0 ml. of 0.2% aqueous nitroso-R-salt solution, 0.5 ml. of 25% sodium acetate solution, and 0.5 ml. of 50% nitric acid, and simmer gently for 1 min. Cool, and dilute to 5.0 ml.

Measure the absorption of the solution in an appropriate micro cell, using Wratten 74 and H503 filters and setting the Spekker at water-to-water 1.20.

Measure the absorption in the same cell of an equal quantity of Hilger electrolytic iron similarly treated as a blank, and relate the difference reading obtained to a prepared calibration curve.

Details of the scope and accuracy are:

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-1.2	± 0.02
2.0	0.0-1.8	± 0.03
1.0	0.0-3.6	± 0.06
0.5	0.0-7.2	± 0.15

Figure 14 shows the calibration curves produced by making known additions of a standard solution

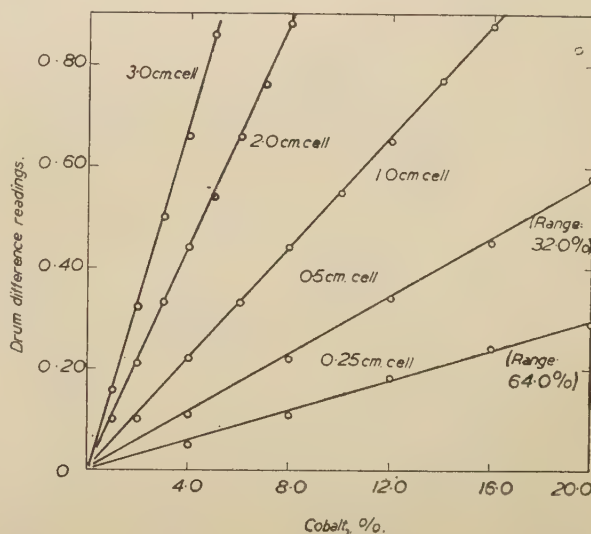


FIG. 15—Graph for the microchemical determination of cobalt in high cobalt content ferrous alloys (see Table V)

of pure cobalt to Hilger electrolytic iron and treating as described.

Method II (Higher Cobalt Content Alloys)

This method depends upon the same reaction as Method I and is used where a large cobalt content is present. Only 0.5 mg. of sample are taken instead of 1.0 mg., and the quantity of nitroso-R-salt is doubled. All other conditions remain the same with the exception of the filter used for the absorption measurement.

Procedure—Dissolve 0.5 mg. of sample in 0.5 ml. of 12.5% Spekker acid in a 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr. 1.20) and evaporate to fumes of sulphur

Cool, add 2.0 ml. of 0.2% aqueous nitroso-R-salt solution, 0.5 ml. of 25% sodium acetate solution, and 0.5 ml. of 50% nitric acid, and simmer gently for 1 min. Cool, and dilute to 5.0 ml.

Measure the absorption of the solution and blank as described in Method I but using Ilford 606 and H503 filters, and relate the difference reading obtained to a prepared calibration curve. A correction of 0.04% for each 10% of chromium present must be applied.

Details of the scope and accuracy are:

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-5.0	± 0.08
2.0	0.0-8.0	± 0.15
1.0	0.0-16.0	± 0.30
0.5	0.0-32.0	± 0.60
0.25	0.0-64.0	± 1.20

Figure 15 shows the calibration curves produced by making known additions of a standard solution of cobalt to Hilger electrolytic iron and treating as described.

Microchemical Determination of Copper in Ferrous Alloys

According to the nickel and chromium content of the material under consideration one of the following methods can be applied.

Method I (Nickel Content less than 1%, Chromium Content more than 4%)

The method depends upon the formation of the complex produced by copper salts with sodium diethyldithiocarbamate in ammoniacal solution, and is based upon the work of Callan and Henderson.¹¹ The complex is prevented from precipitation by the addition of gum acacia solution which acts as a protective colloid, and the interference of iron is avoided by the use of ammonium citrate. Under these conditions and using Ilford 603 filters for the absorption measurements, iron gives a small constant absorption.

Investigation showed that nickel and chromium gave coloured complexes with the reagent, and ultimately, with high concentrations gave rise to precipitates which could not be suppressed even by drastic modification of the conditions. Hence, when the nickel content of the alloy is greater than 1% and the chromium content is greater than 4%, the copper must be determined as described in Method II. The direct method, however, can be applied in the presence of small amounts of these elements by utilizing appropriate correction curves.

Procedure—Dissolve 4.0 mg. of sample in 0.5 ml. of 50% Spekker acid in a 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr. 1.42), and evaporate to fumes of sulphur trioxide. Cool, add 2.0 ml. of 25% ammonium

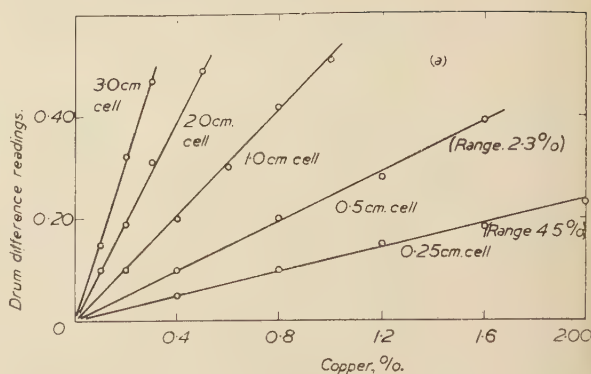


FIG. 16(a)—Graph for the microchemical determination of copper in ferrous alloys (direct method) (see Table V)

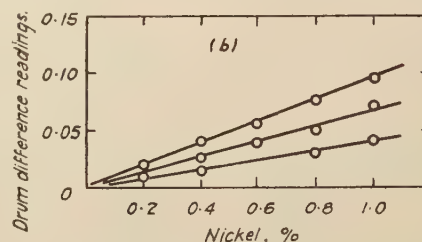


FIG. 16(b)—Correction curves for the presence of 0-1% of nickel when determining copper by the direct microchemical method (see Table III)

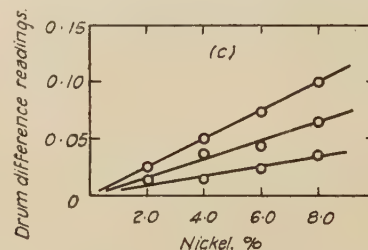


FIG. 16(c)—Correction curves for the presence of 0-8% of nickel when determining copper by the direct microchemical method (see Table III)

TABLE III—Correction data for the Presence of Chromium and Nickel when Determining Copper by the Direct Method

Element, %	Drum Difference Readings		
	3.0-cm. Cell	2.0-cm. Cell	1.0-cm. Cell
<i>Chromium</i>			
2.0	0.025	0.015	...
4.0	0.05	0.035	0.015
6.0	0.075	0.045	0.025
8.0	0.10	0.065	0.035
<i>Nickel</i>			
0.2	0.02	0.01	...
0.4	0.04	0.025	0.015
0.6	0.055	0.04	...
0.8	0.075	0.05	0.03
1.00	0.095	0.07	0.04

citrate solution, 1.0 ml. of 1% filtered gum acacia solution, 2.0 ml. of 50% ammonium hydroxide solution, and 0.5 ml. of filtered 0.5% sodium diethyldithiocarbamate solution, mixing well after each addition.

Measure the absorption of the solution in an appropriate micro cell using Ilford 603 and H503 filters, setting the Spekker at water-to-water 0.80.

Measure the absorption in the same cell of an equal quantity of Hilger electrolytic iron similarly treated as a blank, and relate the difference reading obtained to a prepared calibration curve. Apply such corrections for nickel and chromium as necessary, derived from appropriate correction curves, shown in Fig. 16 (*b* and *c*).

Details of the scope and accuracy are :

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-0.30	± 0.01
2.0	0.0-0.50	± 0.02
1.0	0.0-1.0	± 0.04
0.5	0.0-2.0	± 0.08
0.25	0.0-4.5	± 0.15

Figure 16 (*a*) shows the calibration curves, and the correction-curve data are given in Table III.

Method II (General application)

This method is applicable to all types of ferrous alloys irrespective of their composition, and depends upon the initial separation of the copper as sulphide, followed by filtration using the filter-stick technique. The sulphide precipitate is dissolved, and the copper is determined by the complex given with sodium diethyldithiocarbamate. Using the filter-stick technique for filtration, no transference of the sulphide precipitate is necessary and hence no loss of copper occurs. A certain amount of finely divided sulphur is precipitated on passing hydrogen sulphide, due to the reduction of the ferric iron present, and this appears to act as a collector of the copper sulphide. This sulphur precipitate is not completely destroyed when the precipitated sulphides are dissolved in aqua regia, and a further filtration through the same stick is necessary. This time the filtrate and washings are collected and treated for copper as described in Method I.

Since iron and other interfering elements are removed by the separation procedure the blank reading is not so pronounced, and so for the absorption measurements the most suitable filter for obtaining the maximum sensitivity of the reaction can be used. Consequently Ilford 601 filters are utilized instead of Ilford 603.

Procedure—Dissolve 4.0 mg. of sample in 0.5 ml. of 50% Spekker acid in a wide-mouthed 10-ml. conical flask. Oxidize with 1 drop of

nitric acid (sp. gr. 1.42) and evaporate to fumes of sulphur trioxide. Cool, add 5.0 ml. of distilled water, and warm on the steam bath. Remove from the bath and pass hydrogen sulphide through a micro bubble tube into the solution as it cools. When quite cold, filter through a porcelain filter stick, washing the flask, stick, and precipitate with 2% sulphuric acid saturated with hydrogen sulphide. Reject the filtrate and washings.

Remove the stick and flask, add 0.5 ml. of hydrochloric acid (sp. gr. 1.16) and 0.5 ml. of nitric acid (sp. gr. 1.42), and simmer gently for two or three minutes. Cool, add approximately 1.0 ml. of distilled water, and filter again through the stick, collecting the filtrate in another 10-ml. conical flask. Wash the original flask and stick with cold distilled water, adding the washings to the filtrate. Add 0.5 ml. of 50% Spekker acid to the combined filtrate and washings, and evaporate the solution to fumes of sulphur trioxide.

Cool, add 2.0 ml. of 25% ammonium citrate solution, 1.0 ml. of 1% filtered gum acacia solution, 2.0 ml. of 50% ammonium hydroxide solution, and 0.5 ml. of filtered 0.5% sodium diethyldithiocarbamate solution, mixing well after each addition.

Measure the absorption of the solution and blank as described in Method I but using Ilford 601 and H503 filters, and a 1.20 setting, and relate the difference reading obtained to a prepared calibration curve.

Details of the scope and accuracy are :

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-0.35	± 0.01
2.0	0.0-0.50	± 0.02
1.0	0.0-1.00	± 0.04
0.5	0.0-2.00	± 0.10
0.25	0.0-4.00	± 0.20

Figure 17 shows the calibration curves prepared by making known additions of a standard solution of pure copper to Hilger electrolytic iron and treating as described.

Microchemical Determination of Tungsten in Ferrous Alloys

According to the molybdenum content of the material under consideration one of the following methods can be applied.

Method I (Molybdenum Content less than 0.2%)

Early attempts to determine tungsten by reduction to tungsten blue and by the complex produced with hydroquinone in sulphuric acid were unsuccessful, and a satisfactory method was not obtained until after the publication of a recent paper by Miller¹² on the use of toluene

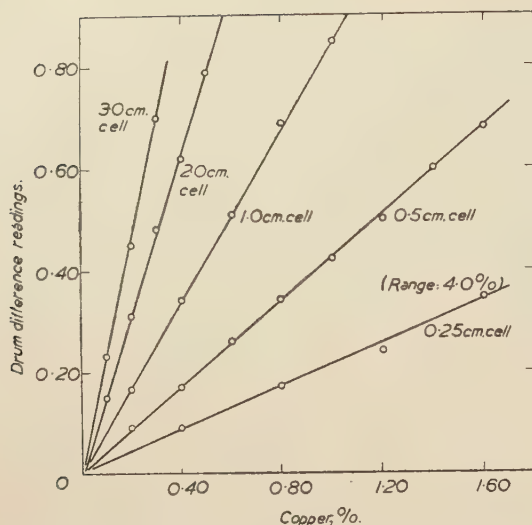


FIG. 17—Graph for microchemical determination of copper in ferrous alloys (separation method) (see Table V)

3-4 dithiol as a qualitative test for tungsten. It was found that by measuring the absorption of the coloured solution produced under standard conditions, the reaction could be made to proceed quantitatively. The absorption of the green-coloured tungsten complex dissolved in amyl acetate was found to be proportional to the tungsten content of the alloy, provided that molybdenum was not present in amounts greater than 0.2%. The complex produced by molybdenum with the reagent was very similar in colour to that produced by tungsten, and the quantity extracted by amyl acetate was found to vary with the extraction conditions, so that allowance for absorption due to molybdenum complex by means of a simple correction curve was not possible. If molybdenum is known to be present in amounts greater than 0.2% the procedure given in Method II must be followed.

Procedure—Dissolve 2.0 mg. of sample in 0.5 ml. of 50% Spekker acid in a 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr. 1.42) and evaporate to fumes of sulphur trioxide. Cool, add 1.0 ml. of 10% stannous chloride solution in hydrochloric acid (sp. gr. 1.16), and warm on the steam bath for 3 min. Add 1.0 ml. of 2% toluene 3-4 dithiol solution in amyl acetate, and warm again on the steam bath for 10 min. with frequent shaking. Transfer warm, to a 25-ml. separating funnel, washing with drops of amyl acetate, and shake well. Allow to separate; remove the steel (lower) layer and shake the remaining ester layer with 6 ml. of hydrochloric acid (sp. gr. 1.16). Allow to separate, and run off the acid (lower) layer. Dilute the ester layer to 5.0 ml. with amyl acetate.

Measure the absorption of the solution in an appropriate micro cell using Ilford 606 and H503 filters setting the Spekker at water-to-water 1.20.

Measure the absorption in the same cell of an equal quantity of Hilger electrolytic iron similarly treated as a blank, and relate the difference reading obtained to a prepared calibration curve.

Details of the scope and accuracy are :

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-1.2	±0.01
2.0	0.0-1.8	±0.02
1.0	0.0-3.6	±0.05
0.5	0.0-7.5	±0.10
0.25	0.0-15.0	±0.20

Figure 18 shows the calibration curves prepared by making known additions of a standard solution of sodium tungstate to Hilger electrolytic iron and treating as described.

The method has proved to be the most satisfactory method yet advanced for the determination of small amounts, e.g., 0.05% of tungsten in steels, and the authors have successfully applied the technique to the routine laboratory determination of small amounts of tungsten in steel on a macro scale.

Method II (General Application)

This method depends upon the formation of the same complex as in Method I but is applicable to all types of ferrous alloys. The interference

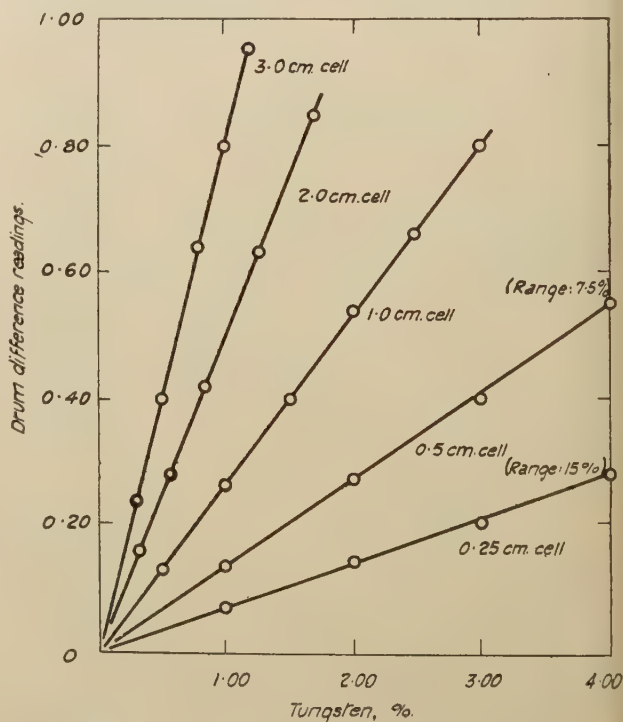


FIG. 18—Graph for the microchemical determination of tungsten in ferrous alloys (see Table V)

of molybdenum is prevented by hydrogen sulphide precipitation, the amount of molybdenum remaining in the solution after the sulphide separation being insufficient to effect the normal procedure for tungsten. The results obtained, whilst not as accurate as those yielded by Method I, are considered reasonably good.

Procedure—Dissolve 2.0 mg. of sample in 0.5 ml. of 25% Spekker acid in a wide-mouthed 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr. 1.42) and evaporate to fumes of sulphur trioxide. Cool, add approximately 5.0 ml. of distilled water, and heat on the steam bath. Pass hydrogen sulphide through a micro bubble tube into the solution as it cools. When quite cold, filter through a porcelain filter stick, washing the flask, stick, and precipitate with 2% sulphuric acid saturated with hydrogen sulphide.

Collect the filtrate and washings, and boil off hydrogen sulphide. Add 0.5 ml. of 25% Spekker acid and 1 drop of nitric acid (sp. gr. 1.42), and evaporate to fumes of sulphur trioxide. Cool, add 1.0 ml. of 10% stannous chloride solution in hydrochloric acid (sp. gr. 1.16), and warm on the steam bath for 3 min. Add 1.0 ml. of 2% toluene 3-4 dithiol solution in amyl acetate, and warm again on the steam bath for 10 min. with frequent shaking.

Transfer warm, to a 25-ml. separating funnel, washing with drops of amyl acetate, and shake well. Allow to separate, remove steel (lower) layer, and shake the remaining ester layer with 6 ml. of hydrochloric acid (sp. gr. 1.16). Allow to separate, and run off the acid (lower) layer. Dilute the ester layer to 5.0 ml. with amyl acetate.

Measure the absorption of the solution and blank as described in Method I, and relate the difference reading obtained to a prepared calibration curve.

The range of the method and the calibration curves are similar to those shown under Method I.

Microchemical Determination of Titanium in Ferrous Alloys

According to the tungsten content of the material under consideration one of the following methods can be applied.

Method I

The method depends upon the formation of the complex given by titanium with thymol in concentrated sulphuric acid solution. The reaction was first recorded by Lehner and Crawford,¹³ and was used as the basis of a qualitative test for titanium. Experiments showed that ferric iron also gave a colour with the reagent

whereas ferrous iron did not, and hence interference from iron was prevented by the addition of a little stannous chloride solution before adding the concentrated sulphuric acid and reagent. Tungsten behaves similarly to titanium and produces a red colour with the reagent, although the reaction is not so sensitive for this element. A direct determination of titanium

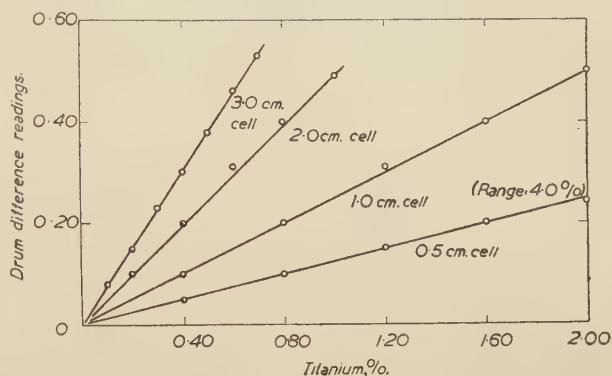


FIG. 19—Graph for the microchemical determination of titanium in ferrous alloys (see Table V)

can consequently only be carried out when the tungsten content of the alloy is known to be less than 0.5%. When the tungsten content exceeds this limit a separation method as described in Method II must be used. A correction must be applied for large amounts of chromium.

Procedure—Dissolve 2.0 mg. of sample in 0.5 ml. of 50% Spekker acid in a 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr. 1.42) and evaporate to fumes of sulphur trioxide. Cool, add 0.6 ml. of 5% stannous chloride solution in 5% hydrochloric acid, and shake well. Add 4.0 ml. of sulphuric acid (sp. gr. 1.84) and shake, and warm until the solution is clear. Cool thoroughly, add 1.0 ml. of 5% thymol solution in sulphuric acid (sp. gr. 1.84), and mix well.

Measure the absorption of the solution in an appropriate micro cell using Ilford 603 and H503 filters setting the Spekker at water-to-water 0.80.

Measure the absorption in the same cell of an equal quantity of Hilger electrolytic iron similarly treated as a blank, and relate the difference reading obtained to a prepared calibration curve, applying a correction of 0.02% for each 10% of chromium present.

Details of the scope and accuracy are :

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-0.60	±0.02
2.0	0.0-1.0	±0.03
1.0	0.0-2.0	±0.06
0.5	0.0-4.0	±0.15
0.25	0.0-8.0	±0.30

Figure 19 shows the calibration curves prepared by making known additions of a standard solution of titanium sulphate to Hilger electrolytic iron and treating as described.

Method II (All Types of Ferrous Alloys)

This method is applicable when the tungsten content of the alloy is greater than 0.5% and depends upon the formation of the thymol complex after separation of tungsten with toluene 3-4 dithiol solution and amyl acetate. The tungsten is removed in the ester layer and the titanium can be determined in the steel layer without further interference.

Procedure—Dissolve 2.0 mg. of sample in 0.5 ml. of 50% Spekker acid in a 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr. 1.42) and evaporate to fumes of sulphur trioxide. Cool, add 1.0 ml. of 10% stannous chloride solution in hydrochloric acid (sp. gr. 1.16), and warm on the steam bath for 3 min. Add 1.0 ml. of 2% toluene 3-4 dithiol solution in amyl acetate, and warm again on the steam bath for 10 min. with frequent shaking. Transfer warm, to a 25-ml. separating funnel with drops of amyl acetate, and shake well. Allow to separate, remove the steel (lower) layer into a 10-ml. conical flask, and shake the ester (upper) layer with 2.0 ml. of hydrochloric acid (sp. gr. 1.16). Allow to separate, and add the acid (lower) layer to the first separation solution. Evaporate the combined solutions to the first appearance of salts, and cool. Add 0.5 ml. of distilled water, warm to dissolve the salts, and add 0.1 ml. of 5% stannous chloride solution in 5% hydrochloric acid. Add 4.0 ml. of sulphuric acid (sp. gr. 1.84), shake, and warm and, if the solution is not clear, filter through a porcelain filter stick. Cool, add 1.0 ml. of 5% thymol solution in sulphuric acid (sp. gr. 1.84), and shake thoroughly.

Measure the absorption of the solution and blank as described in Method I, and relate the difference reading obtained to a prepared calibration curve, applying a correction of 0.02% for each 10% of chromium present.

The range of the method and the calibration curves are similar to those shown for Method I.

Microchemical Determination of Iron in Ferrous Alloys

The method depends upon the formation of the yellow-green coloured complex given by iron with citric acid in ammoniacal solution, the absorption of the complex in solution being proportional to the concentration of iron. The principal interfering element is chromium, for which a simple correction must be applied.

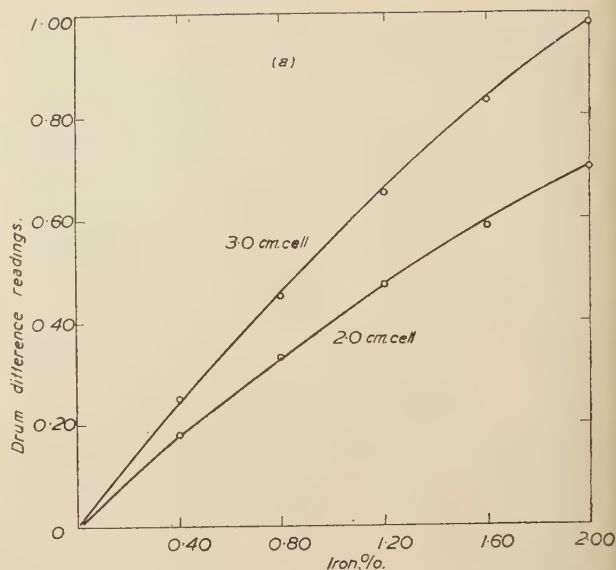


Fig. 20(a)—Graph for the microchemical determination of iron in ferrous alloys (see Table V)

Procedure—Dissolve 2.0 mg. of sample in 0.5 ml. of 25% Spekker acid in a 10-ml. conical flask. Oxidize with 1 drop of nitric acid (sp. gr. 1.42), and evaporate to fumes of sulphur trioxide. Cool, add 2.0 ml. of 25% ammonium citrate solution, 2.0 ml. of distilled water, and 1.0 ml. of 50% ammonium hydroxide solution.

Measure the absorption of the solution in an appropriate micro cell using Ilford 601 and H503 filters, setting the Spekker at water-to-water 1.30.

Measure the absorption in the same cell of all the reagents similarly treated as a blank, and relate the difference reading obtained to a prepared calibration curve, applying a correction derived from an appropriate correction graph, for any chromium present.

Details of the scope and accuracy are :

Micro Cell Size, cm.	Range of Method, %	Average Deviation from Mean Figure, %
3.0	0.0-2.0	±0.04
2.0	0.0-3.0	±0.06
1.0	0.0-6.0	±0.15

Figure 20(a) shows the calibration curves prepared by taking known amounts of a standard solution of Hilger electrolytic iron and treating as described. The correction curve for chromium prepared from a standard solution of potassium dichromate is shown in Fig. 20(b), the data being presented in the accompanying Table IV.

Microchemical Determination of Carbon in Ferrous Alloys

The method developed for the micro determination of carbon was a gravimetric method and

TABLE IV—Correction Data for the Presence of Chromium

Wt. of Chromium, mg.	Drum Difference Readings	
	3.0-cm. Cell	2.0-cm. Cell
0.1	0.04	0.02
0.2	0.075	0.05
0.3	0.12	0.075
0.4	0.15	0.10
0.5	0.19	0.12

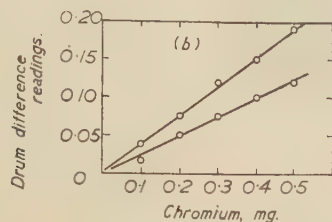


Fig. 20(b)—Correction curves for the presence of chromium when determining iron (see Table IV)

depended upon the combustion of the alloy in a stream of oxygen in which the carbon was converted into carbon dioxide, absorbed in suitable apparatus, and weighed. The apparatus used was a combination of the normal carbon combustion apparatus used in steel analysis, with the organic carbon-hydrogen micro combustion train.

Description of Apparatus

The general arrangement of the combustion train is shown in Fig. 22 and an elevation diagram is shown in Fig. 21. Referring to Fig. 21, the description of the apparatus is as follows:

A small cylinder of oxygen fitted with an Endurance gas regulator is connected to a White-Wright¹⁴ flowmeter (a). The regulator controls and the flowmeter measures the rate of flow of the oxygen through the combustion train. The flowmeter is connected to a narrow-necked bottle (b) which serves the dual

purpose of providing a suitable reservoir of oxygen for the rapid take-up during the actual combustion, and acting as a safety trap to prevent the liquid in the flowmeter being inadvertently carried over into the next portion of the apparatus. This is a White-Wright (*loc. cit.*) preheater (c), the top half of which is packed with platinized asbestos and is heated to a temperature of approximately 400° C. by means of an electric heater, and the bottom half is left empty and is cooled in a beaker of water. The purpose of the preheater is to oxidize to water and carbon dioxide any organic impurities or carbon monoxide which might be present in the oxygen supply and which would otherwise be oxidized in the combustion tube, absorbed, and weighed.

The products formed in the preheater are removed by the purification unit (d). This consists of two Bobranski-Sucharda tubes,¹⁵ the first one packed with soda asbestos and the second packed with anhydrous. To economize in space, the two tubes can be arranged parallel to each other as shown in the diagram. The purification tubes are connected to the side arm of the combustion tube which is fixed in the small heating furnace (f). The combustion tube, of dimensions 30 cm. long by 1 cm. internal diameter, is made of Morgan 'Triangle H' quality porcelain, type T6370, and is provided with reduced end and side arm.

The furnace (f) was not available commercially and was designed and constructed in the laboratory. The heating element consists of 9 ft. of special platinum-alloy wire of 0.024 in. dia. wound on to an alundum former of such a bore that the combustion tube enters with an easy fit. The wire is held in position by coating the former with alundum cement and allowing to dry. It is then inserted into a further refractory tube of Morgan 'Triangle H' quality, type T6239, to secure the heating element and to prevent it coming into contact with the insulating medium. The body of the furnace is made from a metal canister fitted with ends made from asbestos board, suitably held together with screw rods. The ends have suitable apertures which determine the position of the external tube previously described, and between the wall of the canister and the external refractory tube; insulating alumina is packed to ensure the minimum possible loss of heat. The outside of the canister is lagged with two layers of asbestos string as a further insulator.

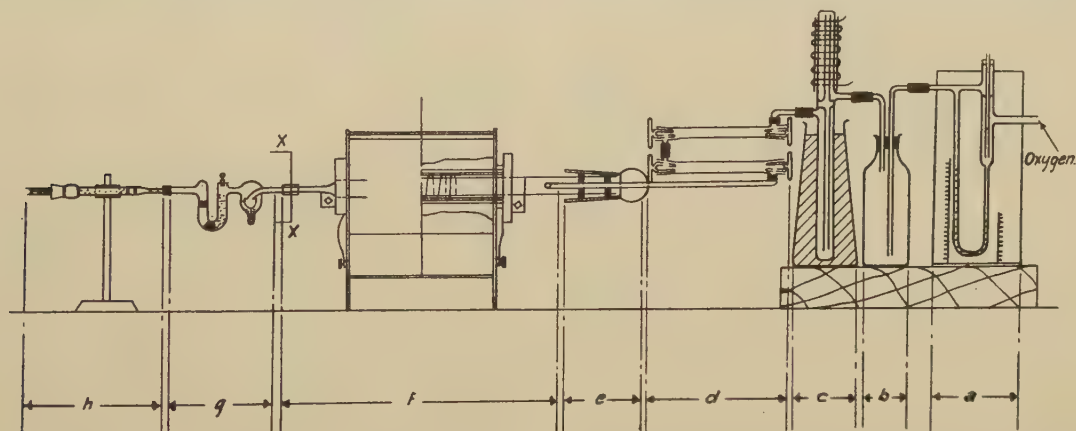


Fig. 21—Diagram of apparatus for the micro determination of carbon and sulphur in ferrous alloys, by combustion

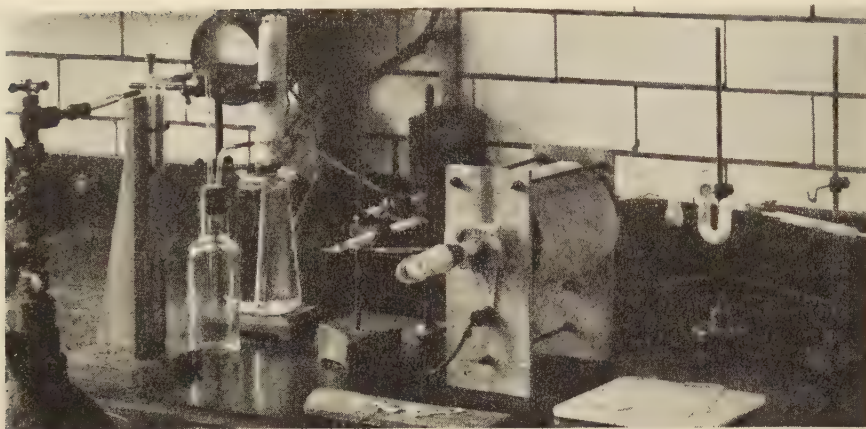


FIG. 22—Apparatus for the micro determination of carbon in ferrous alloys, by combustion

The element is heated by applying a potential of 50 V., and is controlled by a variable resistance. By slowly increasing the current from zero to approximately 7.5 amp. over a period of 2 hr., a temperature of 1250°C. can be reached without risk of damage to the platinum wire. The mouth of the combustion tube (e) is closed by using the two parts of a standard ground-glass joint, size No. 3. The male cone is cut off 1.0 cm. from the end of the ground portion and is secured to the combustion tube by means of two rubber washers. By choosing these washers of suitable thickness an air-tight fit can be ensured. The female cone is sealed off smoothly as near to the ground surface as possible. These two cones provide an air-tight joint which can be readily opened and closed without any danger of small particles of rubber entering the combustion tube.

The reduced end of the combustion tube is connected to a Pregl combined bubble counter and U-tube (g). The bubble counter contains a solution of chromic acid in sulphuric acid (sp. gr. 1.84) and the U-tube contains granulated zinc in the first limb to absorb the acid spray from the bubbler, and anhydrous in the second limb. Suitable plugs of glass wool maintain the reagents in their respective places.

The Pregl absorption tube (*loc. cit.*) (h) is connected to the other end of the U-tube and is filled with soda asbestos with a small quantity of anhydrous at each end. Small plugs of cotton wool are used to separate the reagents and hold them in position. Throughout the apparatus all joints are made glass-to-glass, using artificially aged rubber tubing for all connections before the combustion tube, and wax-impregnated rubber tubing for all connections after. All stoppers are sealed with Kronig glass cement.⁷

Method

Set up the combustion train as previously described and adjust the temperature of the furnace to approximately 1250°C. Carefully wipe the absorption tube with a damp cloth and then with a dry chamois leather, and pass oxygen through the apparatus at a rate of 25 ml./min. In order to saturate all the rubber connections with carbon dioxide, place approximately 50 mg. of a high carbon content steel in a small-size

porcelain micro combustion boat, and introduce it into the hot zone of the furnace. Close the ground-glass joint and pass oxygen for 15 min. Weigh the absorption tube at 10-min. intervals, using the weighing technique described later, until a constant weight is attained. The weight is deemed to have become constant when it does not vary by more than ten micro-grams between two successive weighings. When the tube reaches a constant weight

the apparatus is ready for use.

Weigh out 50 mg. of sample on the micro balance, place into a small porcelain micro combustion boat, and introduce it into the centre of the hot zone of the furnace by using a platinum-wire pusher. Close the ground-glass joint and after 15 min. weigh the absorption tube. The increase in weight of the tube is due to carbon dioxide, from which the percentage of carbon in the alloy can be readily calculated. The sulphur dioxide formed by the combustion of sulphur in the alloy is removed by the chromic acid in the bubble counter which also acts as an indicator, for a steady stream of bubbles shows that a sufficient supply of oxygen is available during the rapid combustion of the alloy.

The combustion boats used were manufactured by C. V. Brindley and were made of aluminous porcelain in two sizes, of overall dimensions 15 × 4 × 3 mm. and 28 × 5 × 5 mm. They proved to be capable of withstanding a temperature of 1400°C. without deformation. In general it was not found necessary to use a flux to facilitate the combustion of the alloys for at the high temperature used most of the alloys were readily combustible. In a few special cases such as highly alloyed corrosion- and heat-resisting steels, an equal weight of Hilger electrolytic iron was mixed with the sample to act as a starter, and in these cases a small predetermined blank figure was deducted from the increase in weight of the absorption tube to allow for the small carbon content of the iron. Should the rate of flow of oxygen as indicated by the bubble counter prove insufficient during the combustion of the larger amount of material it must be increased, but returned to normal when the combustion is finished.

It was not found necessary to adhere to the Pregl wiping treatment⁷ of the absorption tubes

before weighing. The micro balance was placed in close proximity to the absorption tube and train although shielded from the furnace, so that the conditions appertaining inside the case were similar to those surrounding the absorption tube. After a preliminary wiping with a damp cloth and dry chamois leather, the absorption tube was not touched with the bare hands but was always handled with chamois leather, and with these precautions it could be weighed immediately it was placed inside the case.

Microchemical Determination of Sulphur in Ferrous Alloys

According to the amount of sample available, two methods have been devised for the determination of sulphur. Both depend upon the combustion of the alloy in oxygen, but differ in the method used for the determination of the sulphur dioxide formed during the combustion.

The apparatus used in both methods is the same as that used for the micro determination of carbon, with the exception of the bubble counter and U-tube, and the Pregl absorption tube. These are replaced at the point marked X in Fig. 21, by a capillary bubbler tube dipping into a small vessel filled with the absorbing fluid. The alloy sample is weighed into the same type of micro combustion boat as described in the determination of carbon, and it is burnt in a rapid stream of oxygen at a temperature of 1350°C . The sulphur in the steel is oxidized to sulphur dioxide which is carried over and absorbed in the liquid in the absorbing vessel. The two methods use different absorbents for the sulphur dioxide, and both suffer from the disadvantage that the conversion of sulphur to sulphur dioxide is not stoichiometric, so that a conversion factor has to be used. Any variation of the conditions under which the combustion is carried out causes a variation in this conversion factor so that combustion conditions formulated must be adhered to rigidly. The conversion factor is obtained by the combustion of a standard steel of known sulphur content.

Procedure to Method I (Volumetric finish)

Weigh out 50 mg. of alloy into a porcelain micro combustion boat and place the boat in the centre of the furnace hot zone by using a platinum-wire pusher. Close the ground-glass joint, and pass oxygen at the rate of 70 ml./min. Pass the products of the combustion through the bubbler tube into 4.0 ml. of distilled water contained in a 10-ml. conical flask. Continue the oxygen supply for 3 min. after combustion and then remove the flask. Add 0.5 ml. of 20% hydrochloric acid and 0.5 ml. of starch indicator

solution, and titrate with standard potassium iodide-iodate solution from a semi-micro burette until a permanent blue tint is obtained. The standard iodate solution contains 0.22 g. of potassium iodate, 2.10 g. of potassium iodide, and 0.20 g. of potassium hydroxide per 5 litres. One millilitre of this solution is approximately equivalent to 0.040% of sulphur in a 50-mg. sample.

The iodate solution is standardized by carrying out a combustion of a standard alloy with a known sulphur content of the same order as the sample under test, immediately before performing the actual sulphur determinations. The accuracy to be expected from the method is $\pm 0.004\%$.

Method II (Absorptiometric finish)

The amount of sample needed to carry out Method I was often greater than the amount available, and consequently an alternative method using a smaller amount of material and employing an absorptiometric finish was investigated. It was found that when the sulphur dioxide formed during the combustion was passed into a weakly acid solution of potassium dichromate, the dichromate was reduced. Whilst the dichromate solution itself did not provide sensitive absorption measurement in the visual range, it was found that by the addition of diphenylcarbazide to form the purple oxidation complex, very small reductions in dichromate strength were readily detected. A full study of this reaction showed that the sample weight could be reduced from 50 mg. to 10 mg. whilst still maintaining the same degree of accuracy.

Procedure—Weigh out 10 mg. of sample into a porcelain micro combustion boat and place the boat in the centre of the furnace hot zone by using a platinum-wire pusher. Close the ground-glass joint and pass oxygen at the rate of 50 ml./min. for 3 min. Pass the products of the combustion through the bubbler into 4.0 ml. of a solution of potassium dichromate acidified with sulphuric acid contained in a 10-ml. capacity tall beaker. The solution contains 2.25 mg. of potassium dichromate and 20 ml. of sulphuric acid (sp. gr. 1.8) per litre. Continue the oxygen supply for 3 min. after combustion, then remove the beaker and add 1.0 ml. of 0.25% diphenylcarbazide solution in 25% alcohol.

Measure the absorption of the solution in an appropriate micro cell using Wratten 74 and H503 filters, setting the Spekker at water-to-water 1.20.

Measure the absorption of 4.0 ml. of dichromate solution through which oxygen has been passed at the same rate for the same duration

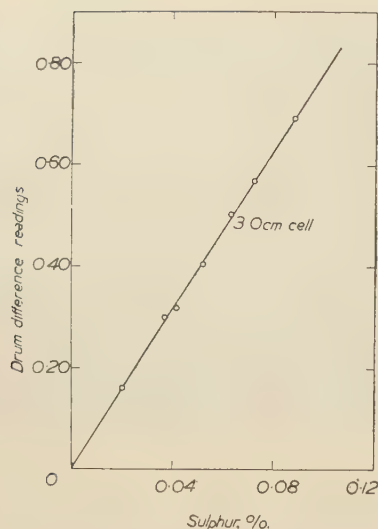


FIG. 23—Graph for the microchemical determination of sulphur in ferrous alloys (diphenylcarbazide method) (see Table V)

of time, and add 1.0 ml. of diphenylcarbazide on completion, as a blank. Relate the difference between these two readings to a calibration curve prepared by burning a series of standard samples of known sulphur content and treating exactly as described above. These combustions should be carried out immediately before the combustion of the samples. Figure 23 shows a calibration curve obtained in this way. The accuracy of the method to be expected is $\pm 0.004\%$.

This concludes the description of the methods developed for the individual determination of the more commonly occurring elements in ferrous alloys. The data from which the graphs have

been derived are summarized in Table V. Other methods for some of the less common elements such as lead, zinc, tin, and zirconium have been devised but have not yet been sufficiently thoroughly investigated, and hence are not recorded in detail in this paper. By following the methods described it is possible to carry out the element determinations on any type of ferrous alloy by taking a separate sample weight for each individual determination. Experience of these methods has shown, however, that although correct and reliable results are obtained, the time required is considerable. Consequently it was thought desirable to attempt to fit several of the separate determinations into some form of composite scheme of analysis.

COMPOSITE SCHEMES OF ANALYSIS

The first attempts were made to carry out the methods for the determination of nickel, molybdenum, and chromium after the determination of manganese, by taking suitable aliquot portions from the solution used for the measurement of the manganese absorption.

It was found possible to apply to this solution the methods previously given for the determination of molybdenum and nickel without interference, but for the determination of chromium by the separation method it was found necessary to destroy the potassium periodate present, by reduction with sulphurous acid. When this treatment was performed no interference with the chromium method was found, and thus it was possible to carry out the analysis for the elements manganese, nickel, chromium, and

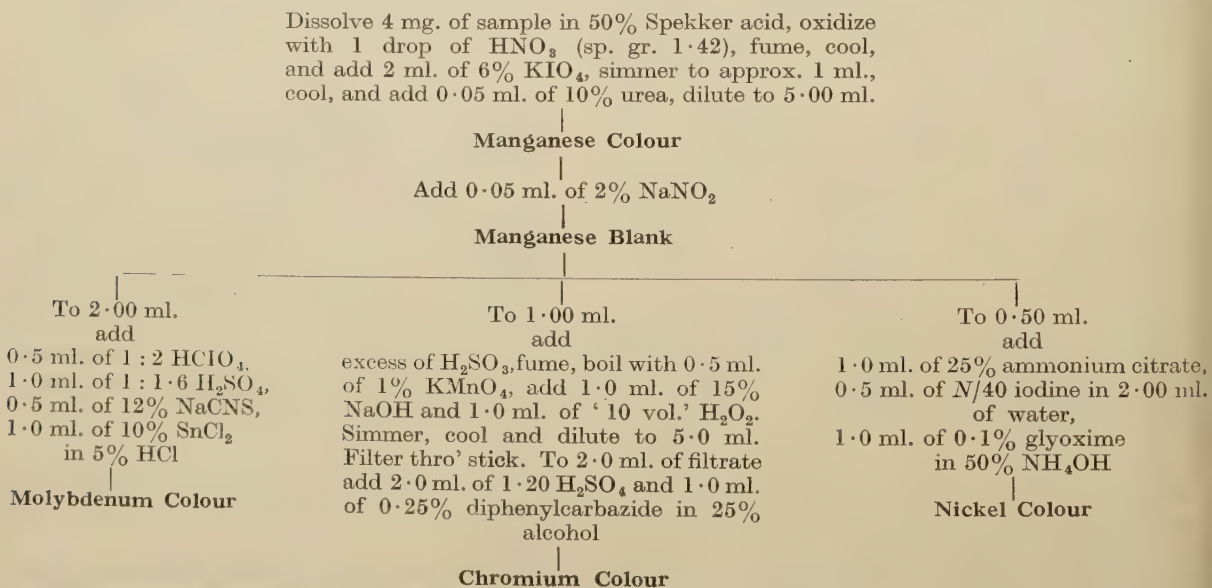


Fig. 24 Composite scheme of analysis for the determination of manganese, nickel, chromium, and molybdenum in ferrous alloys, on a 4-mg. sample

Dissolve 15 mg. of steel in 2 ml. of 50% Spekker acid, oxidize with 4 drops of HNO_3 (sp. gr. 1.42), evaporate to strong fumes, cool, redissolve, and dilute to 15.00 ml.

<p>To 1.00 ml. (1 mg.) add 1 ml. of 0.2% nitroso-R-salt, 0.5 ml. of 25% sodium acetate, 0.5 ml. of 50% HNO_3 Simmer for 1 min., cool, and dilute to 5.00 ml.</p> <p>Cobalt Colour</p>	<p>To 1.00 ml. (1 mg.) add 0.1 ml. of '10 vol.' H_2O_2. Simmer for 15 min. Cool, add 1.0 ml. of 50% H_2SO_4 2.0 ml. of 50% phosphoric acid 0.5 ml. of saturated diphenyl- lamine solution in water. Stand for 15 min. Dilute to 5.00 ml.</p> <p>Vanadium Colour</p>	<p>To 4.00 ml. (4 mg.) add 1 ml. of water; warm on steam bath, pass H_2S thro' capillary tube, filter thro' stick, wash with 2% H_2SO_4 saturated with H_2S_5</p> <p>Iron Colour</p>	<p>To 2.00 ml. (2 mg.) add 2 ml. of 25% ammon. citrate, 1 ml. of 50% NH_4OH</p>
<p>Evaporate 4 ml. to approx. 2 ml., add 2 ml. of 0.6% KIO_4. Simmer, cool, and add 0.05 ml. of 10% urea. Dilute to 5.00 ml.</p> <p>Manganese Colour</p> <p>Add 0.05 ml. of 2% NaNO_2</p> <p>Manganese Blank</p>	<p>To 0.50 ml. (0.5 mg.) add 0.5 ml. of 25% Spekker acid 0.5 ml. of 0.15% AgNO_3. Simmer for 15 min., cool, and add 1 ml. of 25% phosphoric acid 1 ml. of 10% urea, 0.1 ml. of 0.2% NaNO_2, dilute to 5.00 ml., add 0.5 ml. of 0.25% diphenylcarbazide in 25% alcohol</p> <p>Chromium Colour</p>	<p>To 0.50 ml. (0.5 mg.) add 0.5 ml. of 25% Spekker acid, 0.5 ml. of 0.15% AgNO_3. Simmer for 15 min., cool, and add 1 ml. of 25% phosphoric acid 1 ml. of 10% urea, 0.1 ml. of 0.2% NaNO_2, dilute to 5.00 ml., add 0.5 ml. of 0.25% diphenylcarbazide in 25% alcohol</p> <p>Chromium Colour</p>	<p>To 2.00 ml. (2 mg.) add 2 ml. of 25% ammon. citrate, 1 ml. of 50% NH_4OH</p> <p>Iron Colour</p>
<p>To 2.00 ml. add 0.5 ml. of 1.2 HClO_4, 1 ml. of 1:1.6 H_2SO_4, 0.5 ml. of 12% NaCNS, 1 ml. of 10% SnCl_2 in 5% HCl</p> <p>Molybdenum Colour</p>	<p>To 1.00 ml. add excess of H_2SO_4 and fume. Boil with 0.5 ml. of 1% KMnO_4, add 1 ml. of 15% NaOH, 1 ml. of '10 vol.' H_2O_2. Simmer, cool, and dilute to 5 ml. Filter thro' stick; to 2 ml. add 2 ml. of 1:20 H_2SO_4, 1 ml. of 0.25% di- phenylcarbazide in 25% alcohol</p> <p>Chromium Colour</p>	<p>From the filtrate boil off H_2S, cool, and dilute to 10.00 ml., pipette 5.00 ml., and add 0.5 ml. of 25% Spekker acid, 0.05 ml. of HNO_3 (sp. gr. 1.42), fume, cool, and add 1 ml. of 10% SnCl_2 in HCl (sp. gr. 1.16), warm on steam bath for 3 min., add 1 ml. of dithiol (0.2 ml. in 10 ml. of amyl acetate), warm on steam bath for 10 min. Separate in funnel.</p> <p>Chromium Colour</p>	<p>To stick and beaker add 0.5 ml. of HCl (sp. gr. 1.16), 0.5 ml. of HNO_3 (sp. gr. 1.42), boil, cool, and add 1 ml. of water, filter thro' stick and wash with water. To filtrate add 0.5 ml. of 50% Spekker acid, fume, and add 2 ml. of 25% ammon. citrate, 1 ml. of 1% gum acacia, 2 ml. of 50% NH_4OH, 0.5 ml. of 0.5% sodium di- ethyldithiocarbonate</p> <p>Copper Colour</p>
<p>Wash the acetate layer with HCl (sp. gr. 1.16), separate, and dilute layer to 5.00 ml.</p> <p>Tungsten Colour</p>	<p>Evaporate the steel layer to appearance of salts, and add 0.5 ml. of water, 0.1 ml. of 5% SnCl_2 in 5% HCl, 4 ml. of H_2SO_4 (sp. gr. 1.84) 1 ml. of 5% thymol in H_2SO_4 (sp. gr. 1.84)</p> <p>Titanium Colour</p>	<p>Evaporate the steel layer to appearance of salts, and add 0.5 ml. of water, 0.1 ml. of 5% SnCl_2 in 5% HCl, 4 ml. of H_2SO_4 (sp. gr. 1.84) 1 ml. of 5% thymol in H_2SO_4 (sp. gr. 1.84)</p> <p>Titanium Colour</p>	<p>To 2.00 ml. (2 mg.) add 2 ml. of 25% ammon. citrate, 1 ml. of 50% NH_4OH</p> <p>Iron Colour</p>

Fig. 25.—Detailed composite scheme for the analysis of ferrous alloys on a 15-mg. sample.

olybdenum on a single sample weight of 4 mg. The full experimental details for this scheme are given in Fig. 24.

Following this development an attempt was made to fit as many as possible of the individual determinations into a full composite scheme. Starting by dissolving a sample weight of 15 mg. of alloy in 2.0 ml. of 50% Spekker acid followed by subsequent oxidation with nitric acid, and finally diluting to a standard volume of 15 ml., conditions were arrived at where aliquot portions could easily be taken for the determination of manganese, molybdenum, nickel, chromium, cobalt, vanadium, copper, tungsten, titanium, and iron. The experimental details for the production of the coloured complexes from the aliquot portions are similar to those given for the individual determinations and are given in full in Fig. 25. With the exception of carbon, sulphur, silicon, and phosphorus, this scheme of analysis permits the determination of all the elements previously discussed, with the same order of accuracy as described in the individual methods. It will be noticed in this scheme that the methods advanced for chromium are those given in the individual determinations as being suitable for alloys with chromium content not exceeding 1%, but should the alloy be of the stainless or high chromium type the scheme can be suitably modified. The method given for high chromium content alloys can readily be substituted and the scheme modified accordingly as shown in Fig. 26.

Both schemes of analysis described are applicable to any type of ferrous alloy irrespective of its nature and composition, except as regards the limiting chromium content of the first scheme.

Should certain of the elements be absent, or present in small amounts only, however, the whole scheme can be considerably simplified. Thus, should the nickel content of the alloy be found to be less than 1% and the chromium less than 6%, it is not necessary to use the sulphide separation method for the determination of copper, as the direct determination could be substituted and carried out with considerable saving of time. Similarly, should the tungsten content of the alloy be found to be less than 0.5%, it is not necessary to remove the tungsten by the toluene 3-4 dithiol separation before proceeding to the determination of titanium. If the molybdenum content of the alloy is found to be less than 0.2%, then the direct determination of tungsten could be carried out without using the hydrogen sulphide separation.

These shortened methods simplify the full scheme considerably, as shown in Fig. 27, but it is necessary to realize that this scheme must only be followed when the conditions described previously have been fulfilled. In order to use the simplified scheme satisfactorily the determinations must be carried out in the following order, namely: manganese, nickel, molybdenum, cobalt, vanadium, chromium, tungsten, copper, and titanium, so that it can be easily recognized at any stage whether the full or simplified scheme of analysis must be followed.

As a test for the methods described, several samples of British Chemical Standard alloys were analysed by the schemes of analysis detailed in Fig. 27. In order to make the test of the methods as comprehensive as possible, a 0.09-g. sample from each of five standard alloys was given to

TABLE VI—Results Obtained by the Application of the Methods to a Variety of Standard Ferrous Alloys (total wt. of sample 90 mg.)

Steel		C, %	Si, %	Mn, %	P, %	S, %	Ni, %	Cr, %	Mo, %	V, %	W, %	Co, %	Cu, %
B.C.S. 215	Standard analysis	0.93	0.26	0.42	0.038	0.037	0.10	0.02	0.02	...	...	0.005	0.08
	Analyst A ...	0.94	0.26	0.42	0.038	0.040	0.09	0.04	0.02	...	...	0.01	0.09
	Analyst B ...	0.93	0.25	0.42	0.040	0.042	0.08	0.03	0.02	...	...	0.01	0.07
B.C.S. 219	Standard analysis	0.31	0.23	0.58	0.039	0.043	2.64	0.82	0.61	...	...	0.04	0.15
	Analyst A ...	0.32	0.22	0.59	0.038	0.044	2.60	0.81	0.63	...	...	0.02	0.16
	Analyst B ...	0.31	0.22	0.58	0.035	0.043	2.66	0.84	0.61	...	...	0.03	0.16
B.C.S. 211	Standard analysis	0.25	0.30	0.34	0.017	0.010	0.33	13.80	0.09	0.03	...	0.03	0.08
	Analyst A ...	0.26	0.29	0.33	0.020	0.012	0.32	13.80	0.10	0.04	...	0.04	0.10
	Analyst B ...	0.27	0.30	0.32	0.021	0.008	0.32	14.00	0.08	0.02	...	0.02	0.09
B.C.S. 'L'	Standard analysis	3.06	2.26	1.01	0.019	0.031	13.45	3.96	...	...	...	...	4.70
	Analyst A ...	3.08	2.31	0.99	0.022	0.032	13.25	4.01	...	...	...	...	4.66
	Analyst B ...	3.04	2.20	0.98	0.023	0.029	13.20	3.92	...	...	...	...	4.62
B.C.S. 'W2'	Standard analysis	0.71	0.14	0.22	0.026	0.051	0.43	3.32	0.55	0.82	16.12	4.35	...
	Analyst A ...	0.72	0.12	0.24	0.022	0.048	0.44	3.27	0.52	0.78	16.00	4.36	...
	Analyst B ...	0.73	0.11	0.24	0.022	0.049	0.47	3.26	0.51	0.77	15.95	4.30	...

two separate analysts working independently. One analyst (A) was fully conversant with all the methods described, having had at least twelve months' practical experience in the mani-

pulation and technique, whilst the other analyst (B) had had only three months' experience and was not conversant with some of the more complicated separation methods. Each analyst

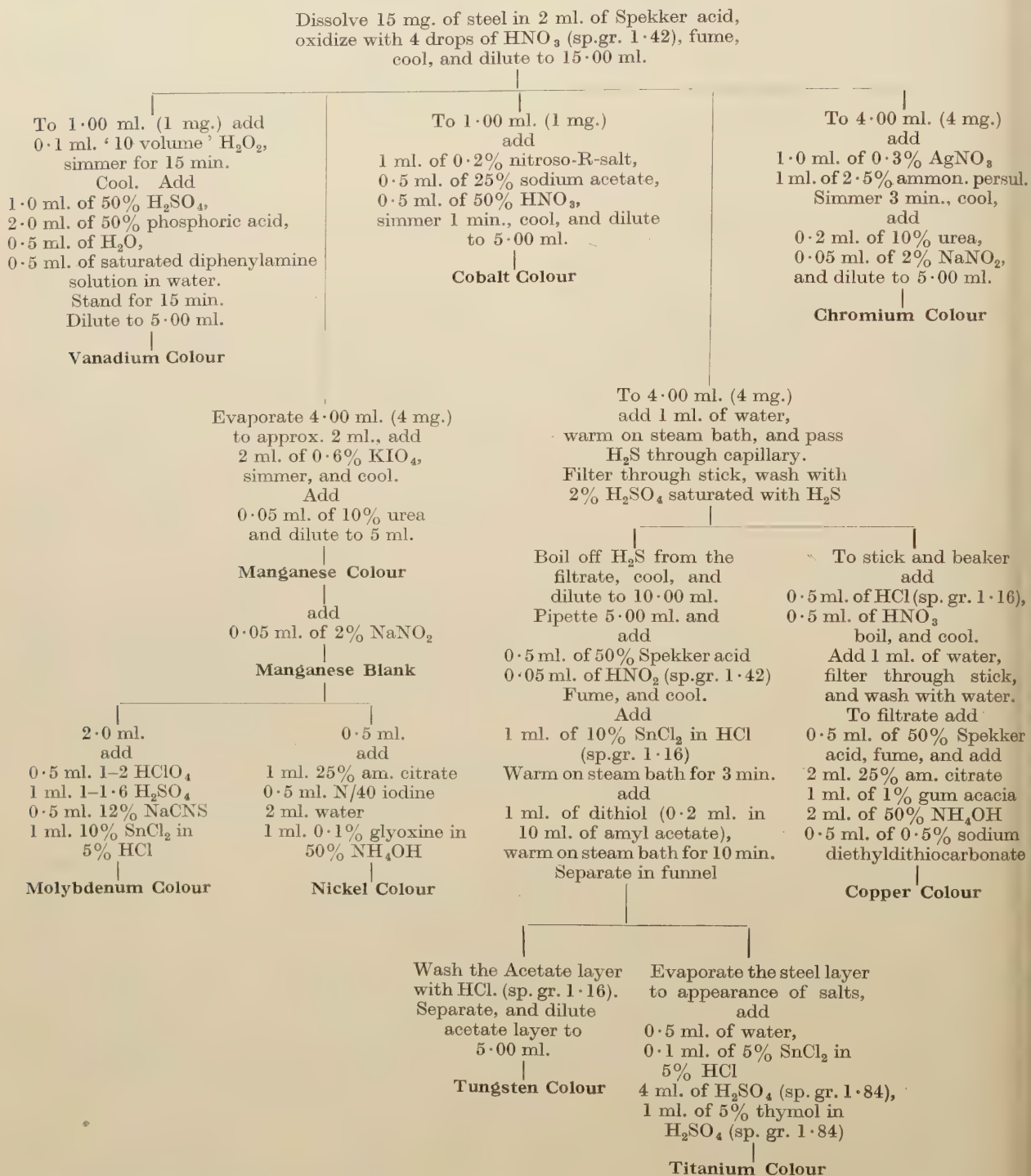


Fig. 26—Detailed composite scheme for the analysis of high chromium content ferrous alloys on a 15-mg. sample

Dissolve 15 mg. of steel, in 2 ml. of 50% Spekker acid, oxidize with 4 drops HNO_3 (sp. gr. 1.42). Evap. to strong fumes, cool, redissolve, and dilute to 15.00 ml.

<p>To 2.00 ml. (2 mg.) add 0.5 ml. of 50% Spekker acid. Fume and add 1 ml. of 10% SnCl_2 in HCl (sp. gr. 1.16). Warm on steam bath, and add 1 ml. of 2% dithiol in amyl acetate. Warm on steam bath for 10 min., shaking frequently. Separate in funnel</p> <p>Wash the acetate layer with HCl (sp. gr. 1.16). Separate and dilute to 5.00 ml.</p> <p>Tungsten Colour</p>	<p>To 1.00 ml. (1 mg.) add 0.1 ml. of '10 volume' H_2O_2. Simmer for 15 min. Cool. Add 1.0 ml. of 50% H_2SO_4. 2.0 ml. of 50% phosphoric acid, 0.5 ml. of H_2O. 0.5 ml. of saturated diphenylamine solution in water. Stand for 15 min. Dilute to 5.00 ml.</p> <p>Vanadium Colour</p>	<p>Fume 4.00 ml. (4 mg.), cool, and add 2 ml. of 25% ammon. citrate, 1 ml. of 1% gum acacia, 2 ml. of 50% NH_4OH, 0.5 ml. of 0.5% sodium diethyl dithiocarbonate</p> <p>Copper Colour</p>	<p>To 1.00 ml. (1 mg.) add 1.0 ml. of 0.2% nitroso-R-salt, 0.5 ml. of 25% sodium acetate, 0.5 ml. of 50% HNO_3. Simmer for one minute, cool, and dilute to 5.00 ml.</p> <p>Cobalt Colour</p>
	<p>Evaporate 4.00 ml. (4 mg.) to approx. 2 ml., add 2 ml. of 0.6% KIO_4, simmer, and cool. Add 0.05 ml. of 10% urea, dilute to 5.00 ml.</p> <p>Manganese Colour</p> <p>add 0.05 ml. of 2% NaNO_2</p> <p>Manganese Blank</p>	<p>Fume 2.00 ml. (2 mg.) and add 0.6 ml. of 5% SnCl_2 in 5% HCl. Shake, and add 4.0 ml. of H_2SO_4 (sp. gr. 1.84), warm until soln. clear, cool, and add 1.0 ml. of 5% thymol in H_2SO_4 (sp. gr. 1.84)</p> <p>Titanium Colour</p>	<p>To 1.00 ml. add excess of H_2SO_4, and fume. Boil with 0.5 ml. of 1% KMnO_4, add 1.0 ml. of 15% NaOH, 1.0 ml. of '10 volume' H_2O_2. Simmer, cool, dilute to 5.00 ml. Filter through stick. To 2.00 ml. of filtrate add 2 ml. of 1:20 H_2SO_4. 1.0 ml. of 0.25% diphenylcarbazide in 25% alcohol</p> <p>Chromium Colour</p>
<p>To 2 ml. add 0.5 ml. of 1:2 HClO_4, 1.0 ml. of 1:1.6 H_2SO_4, 0.5 ml. of 12% NaCNS, 1.0 ml. of 10% SnCl_2 in 5% HCl.</p> <p>Molybdenum Colour</p>	<p>To 0.50 ml. add 1.0 ml. of 25% ammon. citrate 0.5 ml. of N/40 iodine, 2 ml. of water, 1.0 ml. of 0.1% glyoxime in 50% NH_4OH</p> <p>Nickel Colour</p>		

Fig. 27—Simplified composite scheme for the analysis of ferrous alloys with certain elements absent, on a 15-mg. sample

worked unknown to the other and produced results for the complete analysis of the five standard steels. The detailed description of the five alloys was as follows :

B.C.S. 215	...	Plain carbon steel
B.C.S. 219	...	Ni-Cr-Mo steel
B.C.S. 211	...	High chromium stainless-type steel
B.C.S. 'L'	...	Ni-Cr-Cu cast iron
B.C.S. 'W 2'		Co-Va high-speed tool steel

The results obtained by the two analysts are shown in Table VI.

It will be noticed that the two analysts agreed well with each other and that the results obtained as compared with the standard figures adopted are well within the limits of error suggested under the details of the methods and compare favourably with the results obtained by normal standard chemical methods.

As a test of the time taken to complete the full analysis of an unknown alloy, further samples of the high-speed tool steel B.C.S. 'W2' were given to each of the two analysts to ascertain how speedily the results could be obtained, assuming that all solutions necessary had previously been prepared. Both analysts completed the analysis of this difficult alloy in 14 hour's working time, and the results obtained were in good agreement with those previously obtained.

During the past three years considerable use of this new technique has been made in the laboratories in a variety of metallurgical investigations. The wide scope of the problems can best be indicated by reference to the actual nature of the sample examined. Of most frequent occurrence were small ordnance mechanism parts, the weights of which seldom exceeded 1 g., and small ball bearings and ball races which had failed by corrosion in service; the corrosion products rarely exceeding a few milligrams. On many occasions it was desired to carry out an analysis of material whilst subjecting it to the minimum amount of damage, and often the necessity arose for the examination of adjacent and varying areas of the same material in order to throw light on the causes of these variations. Particular application of such problems were, the examination of welded joints and badly segregated materials, the analysis of segregates and isolated non-metallic inclusions, and the examination of varying structures in castings and forgings. The micro-analytical technique was found a useful tool in the study of segregates in steel in supplementing and augmenting the information obtained from the new spectrographic technique for the examination of segregates developed in these laboratories by Barker, Convey and Oldfield.^{16, 17} In all, more than

4000 micro-analytical determinations have now been made.

The investigation of methods for other elements (e.g. lead, zinc, tin, and zirconium) and the modification and further application of existing methods is continuing. It does not appear practicable with the present instruments available to reduce the weight of sample beyond the limits already given, and it has not been found possible to incorporate the methods for the determination of phosphorus, silicon, carbon, and sulphur in a general scheme of analysis. However, it is hoped that new and more sensitive absorptiometers using monochromatic light will shortly be available, and a study of the existing evidence suggests that with these new instruments considerable advances may be made both in the reduction of chemical manipulation and in the increase of sensitivity of absorption measurement. The day does not appear far distant when the total weight required for a complete analysis will be considerably less than the present 80 mg. without sacrifice of accuracy, and the time consumed in weighing will be reduced to a bare minimum if not entirely eliminated.

In conclusion it is desired to thank the Board of Admiralty for permission to publish the details of the work carried out in the Bragg Laboratory, and to acknowledge the help and co-operation of the staff of the microchemical department.

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The Effect of Temperature on the Phosphorus Reaction in the Basic Steelmaking Process*

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SYNOPSIS

Following the previous laboratory investigation of the phosphorus reaction in the basic steelmaking process at 1585° C., the work has been extended to two other temperatures, that is, 1550° C. and 1635° C., employing in each case a series of slags of varying lime content and with compositions covering the normal range of basic practice, the experimental technique being similar in all respects to that already described. It is shown that, at steelmaking temperatures, the empirical relationship between the total lime content of the slag and the phosphorus equilibrium constant $\left(k = (P_2O_5) \left| \left\{ [P]^2 \times (FeO)^5 \right\} \right. \right)$ can be defined by the general linear equation: $\text{Log } k = n \log \Sigma CaO - c$, where the gradient n remains constant whilst c varies with temperature. Application of this relationship in controlling dephosphorization in industry is indicated.

In addition, an X-ray examination of the rapidly quenched slags obtained in the present work has been carried out, and the results confirm the findings regarding the constitution of basic slags previously reported for the work at 1585° C.

INTRODUCTION

A LABORATORY investigation of the phosphorus reaction in the basic steelmaking process has previously been carried out at 1585° C. by melting slag and metal together in an electric-arc furnace in the manner which has already been described in detail.‡ The results showed that an empirical linear relationship existed between the logarithm of the total lime content of the slag and the logarithm of the phosphorus equilibrium constant:

$$\left(k = \frac{(P_2O_5)}{[P]^2 \times (FeO)^5} \right),$$

when both the analytically determined (FeO) and the total iron content expressed as ΣFeO were

used in the equilibrium expression. The relationship was expressed in each case by the following equations:

$$\text{On the basis of (FeO),} \\ \log k_1 = 11.80 \log \Sigma CaO - 21.51 \dots \dots \dots (1)$$

$$\text{On the basis of } (\Sigma FeO), \\ \log k_2 = 10.78 \log \Sigma CaO - 20.41 \dots \dots \dots (2)$$

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The views expressed are the authors' and are not necessarily endorsed by the Sub-Committee as a body.

† Sheffield University.

‡ Balajiva, Quarrell, and Vajragupta, *Journal of the Iron and Steel Institute*, 1946, No. I, p. 115P.

As the previous results were only applicable to $1585^\circ \pm 10^\circ \text{C.}$ it was considered desirable that this work should be extended to other temperatures within the range of normal basic steel-making practice, in order that the effect of temperature upon the above relationship could be assessed in a quantitative manner. It seemed probable that within this range of temperature the general empirical relationship $\log k = n \log \Sigma \text{CaO} - c$ would be valid and that n remained constant whilst c varied with the temperature.

EXPERIMENTAL DATA

With a view to studying the effect of temperature the experimental work has been carried out at 1550°C. and 1635°C. , employing in each case a series of slags of varying lime content and with compositions covering the normal range of basic practice. The experimental technique employed was similar in all respects to that previously described. Altogether 31 melts were carried out, series T_x being at 1550°C. and series T at 1635°C. The metal and slag analyses are given in detail in Table I. In the same Table the values of $\log \Sigma \text{CaO}$, $\log k_1 + 5$ and $\log k_2 + 5$ are also inserted.

EFFECT OF TEMPERATURE UPON THE EMPIRICAL LINEAR RELATIONSHIP BETWEEN $\log \Sigma \text{CaO}$ AND $\log k$

On the basis of analytically determined ferrous oxide content, the results for both temperatures

are illustrated in Fig. 1, where $\log \Sigma \text{CaO}$ is plotted against $\log k_1 + 5$; the crosses represent the melts at 1550°C. and the circles those at 1635°C. By means of the method of least squares the gradients of the corresponding straight lines at 1550°C. and 1635°C. were found to be 13.20 and 11.87 with correlation coefficients of 0.98 and 0.99 respectively. The gradient for the

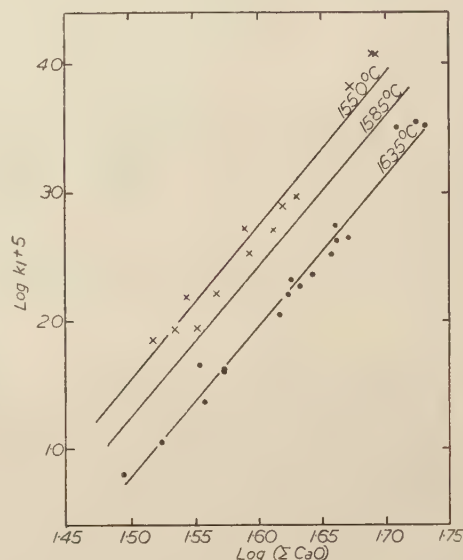


Fig. 1—Effect of temperature upon the linear relationship between $\log \Sigma \text{CaO}$ and $\log k_1 + 5$ on the basis of the analytically determined FeO

TABLE I—Slag and Metal Analyses

Melt No.	Bath Temp., °C.	Time at Temp., min.	Phosphorus in Metal, wt.-%	Slag Analysis, wt.-%								Log ΣCaO	Log $k_1 + 5$	Log $k_2 + 5$
				P_2O_5	CaO	SiO_2	ΣFeO	FeO	Fe_2O_3	Al_2O_3	MnO	MgO		
T_{x1}	1550	30	0.016	9.74	49.2	13.8	18.4	12.7	6.3	1.7	3.3	4.2	1.692	3.256
T_{x2}	1550	30	0.020	8.57	38.8	12.5	27.2	21.0	6.8	2.2	6.3	4.9	1.589	2.158
T_{x3}	1550	30	0.030	8.11	34.2	13.9	31.8	25.4	7.0	1.5	6.4	4.6	1.534	1.443
T_{x4}	1550	30	0.040	8.65	32.9	14.6	29.7	23.8	6.5	1.4	6.9	5.4	1.517	1.369
T_{x5}	1550	30	0.020	9.07	47.0	18.3	16.2	12.8	3.7	2.2	1.6	5.9	1.672	3.308
T_{x6}	1550	30	0.018	8.80	40.9	12.5	28.6	22.1	7.2	1.9	3.3	5.0	1.612	2.152
T_{x7}	1550	30	0.025	8.70	39.2	12.0	27.4	21.1	7.2	2.6	6.5	4.1	1.593	1.955
T_{x8}	1550	30	0.036	8.72	36.9	14.2	26.2	21.1	5.7	1.8	7.0	5.9	1.567	1.736
T_{x10}	1550	30	0.018	8.71	42.7	13.1	26.0	19.6	7.1	1.7	3.1	5.2	1.630	2.354
T_{x12}	1550	30	0.019	8.87	41.6	12.8	26.8	19.9	7.7	2.2	3.3	4.5	1.619	2.250
T_{x13}	1550	30	0.023	8.18	35.0	11.2	33.1	25.2	8.8	2.5	6.0	4.2	1.544	1.590
T_{x14}	1550	30	0.043	8.90	35.7	15.1	27.4	22.3	5.6	2.1	6.9	5.1	1.552	1.493
T_{x15}	1550	30	0.020	9.48	48.9	16.2	17.0	11.5	6.2	2.1	1.5	5.2	1.689	3.223
T_3	1635	30	0.053	9.30	42.9	12.0	23.1	17.8	5.8	2.3	6.1	5.4	1.633	1.702
T_4	1635	30	0.062	8.26	37.4	13.5	27.1	22.2	5.5	1.9	6.5	5.6	1.573	1.167
T_5	1635	30	0.086	7.88	33.4	13.1	29.9	24.9	5.5	1.8	6.9	7.4	1.524	0.649
T_6	1635	30	0.032	9.42	52.9	15.3	17.1	12.1	5.6	2.0	1.2	3.3	1.724	2.799
T_7	1635	30	0.030	8.77	45.5	12.5	25.8	19.7	6.8	1.5	2.7	4.0	1.658	1.930
T_8	1635	30	0.044	9.49	42.3	12.5	24.8	18.8	6.6	2.3	5.8	3.7	1.626	1.718
T_9	1635	30	0.061	8.08	36.1	12.7	30.4	24.8	6.2	1.6	6.4	6.0	1.558	0.922
T_{10}	1635	30	0.064	7.37	31.2	11.9	37.0	31.0	6.6	1.5	6.2	6.5	1.494	0.414
T_{11}	1635	30	0.041	9.31	53.8	15.4	14.6	11.1	3.8	2.0	1.1	5.0	1.731	2.921
T_{12}	1635	15	0.030	9.17	51.2	14.5	18.1	12.6	6.2	1.9	1.3	5.3	1.709	2.720
T_{13}	1635	30	0.041	8.30	41.4	11.6	29.0	21.3	8.5	1.7	2.8	6.9	1.617	1.382
T_{14}	1635	30	0.031	8.31	42.1	11.7	29.4	22.2	7.9	1.4	2.8	5.2	1.624	1.595
T_{15}	1635	30	0.060	9.91	43.9	12.8	22.8	16.4	7.0	2.5	5.9	4.2	1.643	1.650
T_{16}	1635	30	0.039	8.48	46.0	14.8	21.4	16.8	5.5	3.3	1.5	5.4	1.663	2.094
T_{17}	1635	30	0.033	8.43	46.9	13.6	23.2	17.7	6.1	3.1	1.4	3.9	1.671	2.061
T_{18}	1635	30	0.053	7.13	37.4	11.3	28.2	22.8	5.9	3.1	5.8	8.0	1.573	1.154
T_{19}	1635	30	0.059	7.08	35.8	11.5	26.5	21.4	5.6	2.9	10.5	5.7	1.554	1.192
T_{20}	1635	30	0.027	4.53	45.8	15.1	21.6	16.2	6.1	3.2	5.8	4.1	1.661	2.121

previous 88 melts at 1585° C. was 11.80, which is very close to the value of the gradient obtained for 1635° C. The value of the slope for 1550° C., however, is somewhat higher compared with the values of the slope for the other two temperatures, but this discrepancy is probably due to the greater experimental errors involved in the low-temperature region where the slag is comparatively more viscous. It should also be pointed

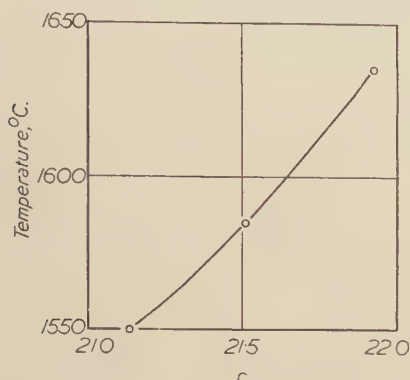


FIG. 2—Variation with temperature of c for the equation: $\log k_1 = 11.80 \log \Sigma \text{CaO} - c$

out that the number of melts in this case is rather small and better agreement would be expected if the number of observations was increased.

Within experimental errors it seems reasonable, therefore, to assume that the gradient of the empirical linear relationship between $\log \Sigma \text{CaO}$ and $\log k_1 + 5$ is constant within the range of steelmaking temperatures. Owing to the fact that the value 11.80 was obtained from the experimental results of 88 melts, more weight should be attached to this figure as representing the most accurate value of the gradient. Straight lines have therefore been drawn through the means of the results for 1550° C. and for 1635° C. parallel to the straight line for the previous 88 melts at 1585° C., as shown in Fig. 1. The equations for these three straight lines are:

At 1550° C., $\log k_1 = 11.80 \log \Sigma \text{CaO} - 21.13$.

At 1585° C., $\log k_1 = 11.80 \log \Sigma \text{CaO} - 21.51$.

At 1635° C., $\log k_1 = 11.80 \log \Sigma \text{CaO} - 21.92$.

It will be seen from Fig. 1 that for a given value of $\log \Sigma \text{CaO}$ the value of $\log k_1 + 5$ decreases with increasing temperature in accordance with the exothermic nature of the phosphorus reaction.

In Fig. 2 the numerical values of c given by the above equations are plotted against the corresponding temperatures and a smooth curve is drawn through the points. It will be noted that the points could well be represented by a straight line, but a curve of the type indicated in Fig. 2 is compatible with theoretical considerations based

on the van't Hoff Isochore and has therefore been taken as the best representation of the points until further evidence is available. The use of the curve will draw attention to the errors likely to be associated with any extrapolation outside the temperature range of the present work. If this is accepted the phosphorus reaction in the basic steelmaking process is therefore empirically defined by the equation:

$$\log k_1 = 11.80 \log \Sigma \text{CaO} - c$$

and the value of c at any temperature within the range covered by the present work can be read off from the curve in Fig. 2. The practical application of this relationship in controlling the phosphorus removal in the steel bath has already been pointed out in the previous paper, and in the light of the present work control charts for any temperature within the normal range of basic steelmaking practice can be drawn in a similar manner.

In dealing with the results obtained under industrial conditions, it should be remembered that there is a possibility of a systematic temperature difference between the temperatures measured in industrial furnaces and those determined in this laboratory work. For practical control in industry it is desirable that the industrial data for a given temperature should be plotted in the manner pointed out and a straight line representing the relationship for that particular temperature under industrial conditions could be drawn through the means of all the points with a slope of 11.80.

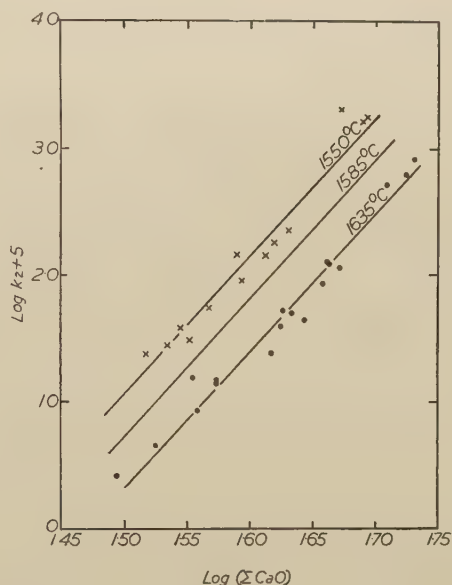


FIG. 3—Effect of temperature upon the linear relationship between $\log \Sigma \text{CaO}$ and $\log k_2 + 5$ on the basis of total FeO

On the basis of total iron content expressed as (ΣFeO) the results for 1550°C. and 1635°C. are plotted in Fig. 3, and by means of the method of least squares the gradients of the lines for the two temperatures were found to be 11.60 and 10.40 with correlation coefficients of 0.98 and 0.99 respectively. For reasons which have been discussed in the preceding case, the slope of the lines for these two temperatures is also assumed to be the same as that of the line for the 88 results at 1585°C. , as shown in Fig. 3. The equations for the three straight lines are:

$$\text{At } 1550^\circ\text{C., } \log k_2 = 10.78 \log \Sigma\text{CaO} - 20.08.$$

$$\text{At } 1585^\circ\text{C., } \log k_2 = 10.78 \log \Sigma\text{CaO} - 20.41.$$

$$\text{At } 1635^\circ\text{C., } \log k_2 = 10.78 \log \Sigma\text{CaO} - 20.83.$$

The variation of c with temperature in this case is illustrated by the curve in Fig. 4. On the

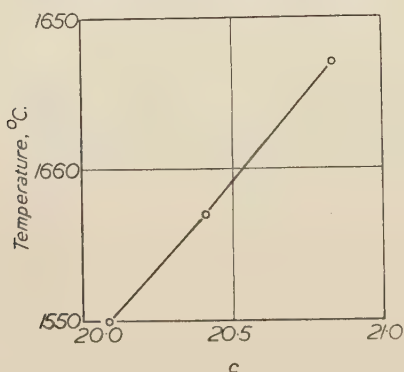


FIG. 4—Variation with temperature of c for the equation: $\log k_2 = 10.78 \log \Sigma\text{CaO} - c$

basis of (ΣFeO), therefore, the phosphorus reaction is defined empirically by the equation:

$$\log k_2 = 10.78 \log \Sigma\text{CaO} - c$$

where the value of c at any temperature within this range can be obtained from the curve in Fig. 4. This empirical relationship on the basis of total iron content can similarly be applied in the practical control of dephosphorization.

Winkler and Chipman* have recently published the results of their laboratory work on the distribution of phosphorus between liquid metal and basic slags but, unfortunately, examination of their analytical data reveals that most of the slags fall outside the range of normal basic practice. However, an attempt has been made to correlate the relationship between $\log \Sigma\text{CaO}$ and $\log k$ from their data; all the fluorspar-free melts for the temperature $1585^\circ \pm 10^\circ\text{C.}$ have been chosen and the results are plotted in Fig. 5. It is interesting to note that all the points could satisfactorily be represented by a straight line

of the same gradient as that of the authors' results for the same temperature, the latter being indicated by dotted lines in the same Figure. The fact that the two straight lines obtained from two independent sources of experimental results are not coincident is to be attributed to a systematic temperature difference already mentioned above.

In order to verify the effect of temperature on the empirical relationship a few melts of lime-silica ratio greater than 2 for various other temperatures were also chosen at random from the same data and the values of $\log k$ plotted against the corresponding $\log \Sigma\text{CaO}$. Although the scatter of the points was rather marked in this case, it was found in general that for a given value of $\log \Sigma\text{CaO}$ the effect of increasing temperature was to lower the value of $\log k$, in agreement with the present experimental findings.

THE CONSTITUTION OF QUENCHED SLAGS

More than half the water-quenched slags obtained in the present work have been examined by the X-ray powder method, using a 9-cm. dia. camera and a cobalt target. The patterns revealed no difference in constitution from those of the slags obtained in the work at 1585°C. , but confirmed the previous findings that quickly quenched

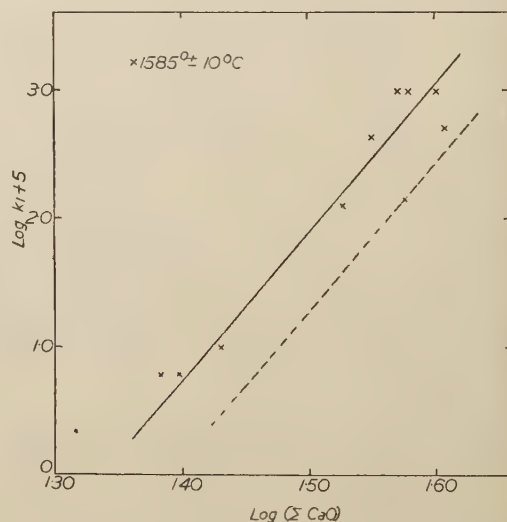


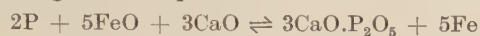
FIG. 5—Winkler and Chipman's results plotted on the basis of $\log \Sigma\text{CaO}$ and $\log k_1 + 5$

slags consist of three main constituents, viz., (1) a lime-silicophosphate solid solution, (2) dicalcium ferrite, possibly in solid solution with brownmillerite ($4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$), and (3) an oxide phase consisting chiefly of FeO , MgO , and MnO in solid solution.

The results obtained in the present work have been treated on the assumptions of the probable

* Winkler and Chipman, *Metals Technology*, 1946, vol. 13, April, Technical Publication No. 1987.

liquid-slag constitution in the manner similar to the previous work at 1585° C. The values of \log (free-lime) were plotted against the corresponding values of $\log k$ calculated on the molecular per cent basis for both temperatures. It was found that all the points for 1550° C. lay above the line for 1585° C., whilst all but three of the points for 1635° C. were below, showing the effect of temperature upon the phosphorus equilibrium conditions on the basis of the above assumptions. The trend of the experimental points for 1550° C. could reasonably well be represented by a straight line of comparable gradient to that of the line for 1585° C.; the gradient of the points for 1635° C., on the other hand, was much greater than 3, which is contrary to what would be expected according to the equation:



The present method of treatment cannot therefore be regarded as satisfactory and it would be unwise to make any further speculation concerning the fundamental nature of the phosphorus reaction, especially at this stage when sufficient knowledge of the physical chemistry of the liquid slag is still lacking.

CONCLUSION

The work carried out at 1550° C. and 1635° C. indicated that, within the range of normal basic steelmaking temperatures, the empirical linear relationship between $\log \Sigma CaO$ and $\log k$, established previously in the work at 1585° C., is also valid, and that the gradient n for the general equation $\log k = n \log \Sigma CaO - c$ remains constant whilst c varies with temperature. On the basis of analytically determined (FeO) the equation is $\log k_1 = 11.80 \log \Sigma CaO - c$; on the basis of total iron content expressed as (ΣFeO) the equation is $\log k_2 = 10.78 \log \Sigma CaO - c$, and the variation of c with temperature is in each case represented in a graphical form. In agreement with the previous work it is found that this empirical relationship is independent of slag compositions within the wide range examined, and if this is also valid under industrial conditions the practical control of dephosphorization in a steel bath would be considerably simplified, since it is found that, for a given temperature, the main controlling factors are the (CaO), (FeO), and (P_2O_5) contents of the slag.

The constitution of the rapidly quenched slags obtained for these two temperature ranges also consists of three main constituents, namely, (a) a solid solution of dicalcium silicate and tricalcium phosphate, (b) dicalcium ferrite with possibly brownmillerite ($4CaO.Al_2O_3.Fe_2O_3$) in

solid solution, and (c) an oxide phase consisting chiefly of FeO, MgO, and MnO in solid solution.

No attempt has been made to evaluate the equilibrium constant or the heat of reaction, owing to the lack of sufficient knowledge regarding the slag constitution in the molten state.

ACKNOWLEDGMENTS

The authors wish to express their great appreciation of the continued interest and encouragement which they have received from Professor J. H. Andrew, D.Sc., throughout this work. Thanks are also due to the members of the staff of the Metallurgical Department, the University of Sheffield, for their help.

The investigation was undertaken for the Ingots Committee of the Joint Research Council, whose generous financial support has rendered this work possible.

RESEARCH REPORTS of the

British Iron and Steel Research Association

Attention is drawn to the following list of recently issued research reports which are available only to Members of the British Iron and Steel Research Association.

VON HOFE. "*Comparison of Different Types of Cyclone Dust Catchers.*" Reference IM/C.

This is a translation of a German report on the comparative performance of three designs of cyclone dust catcher installed at Messrs. Krupp's Rheinhafen Works.

"*Summary of the Proceedings of the Twelfth Blast Furnace Conference.*"

Already circulated to all members of the Blast Furnace Conference. A limited number is still available on request. Full reports are given of the papers and discussion. The subjects are "Blowing Out," "Manufacturing of Foundry Iron in a Modern Furnace," "Stack Cooling" and "Drying the Hearth."

"*Reports on Gas Pickling and Electrolytic Pickling.*" Reference MW/C/r/7.

Short notes and references to the information available on gas and electrolytic pickling are given with some comments on their advantages and disadvantages as compared with acid pickling.

DUNCAN, R. N. "*Notes on Ingot Moulds.*" Reference SM/BA/5/46.

Describes the more common defects found in Ingot moulds at Parkhead Steel Works, and the results of action taken to avoid cracking and crazing of moulds.

JACKSON, A. "*Crespi Bottoms in Germany for Open-Hearth Furnaces.*" Reference SM/A/2/46.

'Crespi' bottoms used successfully since 1942 in eleven German furnaces are described, with details of the analysis, grading and preparation of the material.

A Photo-Electric Roof Pyrometer for Open-Hearth Furnaces*

By T. Land, M.A., F.Inst.P.†

SYNOPSIS

A description is given of a photo-electric pyrometer, employing a selenium barrier-layer photo-electric cell, which has been developed for the measurement of open-hearth furnace roof temperatures. In Part I the reasons are given for choosing a photo-electric instrument in preference to other types of radiation pyrometers. Part II describes the construction, installation, and operation of the pyrometer, and Part III is a discussion of the errors introduced in the measurements by the presence of flame in the furnace. The pyrometer has given excellent service for a period of six months, with very little maintenance, and no measurable change of calibration occurred during this period.

INTRODUCTION

THE control of the temperature of the roof of an open-hearth melting furnace is a matter of great importance in steelmaking. The roof must be maintained at as high a temperature as possible if rapid melting is to be attained, but a fault in judgement in overheating the roof can have disastrous consequences. For this reason a roof pyrometer is more than desirable, but it must be entirely reliable or it will prove worse than useless. Some two years ago it was decided to develop a roof pyrometer for use on a 50-ton acid open-hearth furnace, operated from producer gas and used in melting a wide range of carbon and alloy steels. Careful consideration was given to the choice of the type of instrument for this purpose. It was felt that none of the existing instruments was thoroughly satisfactory, and it was therefore necessary to develop a new instrument, which is described in this paper.

In Part I the factors influencing the choice of the method of measurement are described. In Part II the instrument itself is described, and Part III forms a discussion of the accuracy of the indicated temperature.

PART I—THE CHOICE OF THE METHOD OF MEASUREMENT

Several different methods of measurement of the temperature of the hot surface of the roof are available, and all have their disadvantages. Some initial experiments were made using a rare-metal thermocouple inserted through the roof

with the hot junction as nearly as possible in the plane of the inner surface. These were abandoned for two main reasons. Firstly, the maintenance of the couples under these severe conditions of temperature over long periods proved very difficult. Secondly, the large temperature gradient in the roof (approximately 100° C./in.) raises serious difficulties. So large a gradient may cause errors due to conduction of heat along the thermocouple wires and imperfect equality in temperature between the thermocouple and the roof surface. Furthermore, as the roof burns away, the thermocouple is left protruding from the roof surface, and the junction is no longer in the plane of the hot surface. For these reasons attention was turned to radiation methods.

Errors of Radiation Pyrometers

Radiation methods have their own difficulties and unavoidable errors. So long as the flame is present the furnace is not a perfect black-body enclosure, and the indication of a radiation pyrometer of any type must be influenced to some degree by the reflection of radiation from the flame. The error introduced by the flame radiation is discussed in Part III. The conditions of

* Paper No. SM/AA/1/1946 submitted by the Sub-Committee on Open-Hearth Instruments of the Steel Practice Committee (Steelmaking Divisional Panel), received 29th August, 1946. The views expressed are the author's and are not necessarily endorsed by the Sub-Committee as a body.

† Research Department, Messrs. William Jessop and Sons, Ltd., Sheffield.

measurement introduce two other factors which are of importance. The radiation received by the pyrometer has to pass through several feet of the furnace atmosphere, which will contain significant quantities of carbon dioxide and water vapour. These compounds have absorption bands in the infra-red, so that at certain regions in the infra-red spectrum the radiation received by the pyrometer will be dependent upon the temperature and composition of the furnace gases as well as upon the temperature of the roof. It is therefore important to choose a pyrometer which is insensitive to these regions of the spectrum.

The conditions of measurement on an open-hearth furnace are very severe, and it is difficult to avoid all traces of dirt and smoke in the optical system. It is therefore important to employ a method which will reduce to a minimum the effects of any such obstructions in the optical path.

The effect of such obstructions depends upon the wavelength range used in the pyrometer. The mirror type of radiation pyrometer is sensitive to all wavelengths and the response of the instrument is proportional to the 4th power of the absolute temperature. When a lens is used or a glass screen is interposed, all radiation of wavelength greater than about 2.5μ is eliminated, and the response of the instrument is approximately proportional to the 6th power of the absolute temperature. When visible radiation is used, as in photo-electric pyrometers, the response is approximately proportional to the 12th power of the absolute temperature. Thus, if the dirt and smoke in the optical system absorb 10% of the incident radiation, this will cause errors of 50° C. at 1700° C. with a total radiation pyrometer, 30° C. with a lens-type radiation pyrometer, and only 15° C. with a photo-electric pyrometer.

Another important factor is the speed of response and stability of the instrument. Many radiation pyrometers exhibit the effect known as "after-creep," which means that when the pyrometer is exposed to a constant source of radiation, the response of the instrument does not immediately reach a steady value, but gradually increases over a period of minutes. This defect can be reduced to satisfactory proportions by careful design, but some commercial instruments are far from satisfactory in this respect.

A reverse effect is noticeable in barrier-layer photo-electric pyrometers, which exhibit "drift" or "fatigue," so that on exposure to a constant source of illumination the cell current decreases with time. However, barrier-layer cells are now available in which this effect is reduced to negligible proportions, and a method of rapidly select-

ing suitable cells has been described by Hall.¹

A further difficulty with radiation pyrometers with lens focusing is caused by the lens dispersion. In order to obtain a large e.m.f. it is usual to employ a lens working at a large aperture (say, $f/2.5$), and since the lens transmits radiation up to about 2.5μ , the focal plane for visible light does not coincide with the focal plane for the infra-red radiation which carries the major part of the radiant energy. As a result it is possible for the visible image of the hot object to appear to cover the thermocouple disc when the disc is not by any means fully illuminated with infra-red radiation. There can therefore be some difficulty in deciding whether the object size is satisfactory.

Photo-Electric Pyrometers

It will be seen that the photo-electric pyrometer offers definite advantages over the radiation pyrometer. It remains to discuss the different types of photo-electric cell that are available. These are of two main types. The first is the emission cell, which is similar in appearance to a radio valve and operates by the emission of photo-electrons from a photo-sensitive layer of potassium, caesium, or other metals. The envelope may be either evacuated or filled with an inert gas at low pressure. Gas-filled cells are more sensitive but less stable than vacuum cells.

Under suitable conditions vacuum cells are extremely sensitive and accurate measuring devices, and have been used commercially in pyrometers for measuring rolling-mill and other temperatures. They must, however, be used in conjunction with suitable amplifying equipment with its attendant complication and expense.

The barrier-layer cell has only recently become a precise measuring device, and some prejudice against its use still prevails. Hall² has shown, however, that highly satisfactory cells are available and further progress has now placed the best cells above suspicion.

The cell used in the present pyrometer is the size and shape of a halfpenny. It consists of a disc of iron coated on one side with a photo-sensitive layer of selenium which has a transparent metallic coating on its surface. Such cells are cheap and robust and are easily incorporated in an instrument such as that described in this paper. The temperature coefficient of the cell is about 0.1–0.2% per °C., which reduces ambient temperature errors to 1° or 2° C. in the indicated temperature in a pyrometer enclosed in a water-jacket.

The barrier-layer cell produces a current large enough to operate directly an indicating or recording micro-ammeter which can be calibrated

TABLE I—*Details of Various Types of Pyrometers*

Type of Pyrometer	Wavelength Range	Effect of Gas Absorption by CO ₂ and H ₂ O	Effect of Smoke and Dirt. (Error at 1700° C. for 10% loss of radiation)	Stability	Speed of Response	Comments
(1) Total radiation, mirror focusing	All wavelengths ...	Serious ...	50° C.	Can be good	Can be fairly good, not always so in commercial instruments	Effect of reflected flame radiation is small and calculable, but instrument covers CO ₂ and H ₂ O absorption bands, which may cause serious errors
(2) Partial radiation, mirror focusing, with glass absorption	Visible light and near infra-red down to about 2.5 μ	Slight ...	30° C.	Can be good	As (1) ...	A possible instrument; not too good in effect of smoke and dirt; speed of response may be poor in some types
(3) Partial radiation, lens focusing	Visible light and near infra-red down to about 2.5 μ	Slight ...	30° C.	Can be good	As (1) ...	Lens dispersion can cause serious errors in estimating size of object required; effect of smoke and dirt and comments on speed as (2)
(4) Photo-electric, gas-filled cell	Visible light and/or near infra-red, according to type of cell used	None with suitable cell	10-25° C.	Poor ...	Good ..	Not satisfactorily stable
(5) Photo-electric vacuum cell	Visible light and/or near infra-red	None with suitable cell	10-25° C.	Good ...	Good ...	Requires amplifier. Could be quite a satisfactory pyrometer, but complicated
(6) Photo-electric barrier-layer cell	Visible light ...	None ...	15° C.	Good with selected cells	Good ...	Simple and accurate, and therefore selected for use

in temperature, or an amplifier may be used in conjunction with a large illuminated temperature indicator.

The author³ has previously shown that a photo-electric pyrometer can be calibrated in the laboratory against a standard tungsten-ribbon filament lamp, so that the calibration can be established before the instrument is installed, and checked at intervals if desired. This result can only be attained with a radiation pyrometer if an extended high-temperature black-body source is available, and this is not easily obtained.

The balance sheet of the various types of pyrometers is set out in Table I.

It will be seen that there are two or three different types which could be developed to give a satisfactory temperature measurement. The barrier-layer photo-electric type was chosen because of its simplicity of construction and the small effect of smoke and dirt in the optical path. It was also considered important to have a pyrometer which could be rigorously calibrated before installation.

PART II—THE DESIGN AND INSTALLATION OF THE PYROMETER

The use of a barrier-layer photo-electric cell in the measurement of high temperatures is not new, and for details of earlier work reference should be made to papers by Sosman⁴ and by Dobbins, Gee, and Rees.⁵ Larsen and Shenk⁶ have described the application of such a pyro-

meter to the measurement of open-hearth roof temperatures. These workers relied upon empirical calibration of the pyrometer by comparison with a disappearing-filament pyrometer.

The use of barrier-layer cells in temperature measurement has recently been discussed by Hall² and by the author,³ and the calibration can now be established with precision in terms of the laws of radiation and the spectral response of the photocell. Furthermore, the pyrometer can be calibrated by focusing it upon a standard tungsten-ribbon filament lamp, the brightness temperature of which is known in terms of the lamp current. With the latest available photo-electric cells the barrier-layer photo-electric pyrometer has therefore attained a precision and reliability which is probably better than that of the average commercial disappearing-filament pyrometer, and it has the considerable advantage of continuous indication.

The optical system of the present instrument may be seen from Fig. 1, and comprises a lens, a photocell, and two stops, each having a 7-mm. dia. aperture, placed between lens and cell and separated by a distance of 15 cm. The cell can be moved out of the optical path by means of a lever at the back of the pyrometer, and a second lens then throws an image of the cell stop on to a ground-glass screen. This enables the operator to observe any obstructions in the optical path. The most probable position of an obstruction is in the hole in the furnace wall and the focal length of the main lens is therefore selected so that the

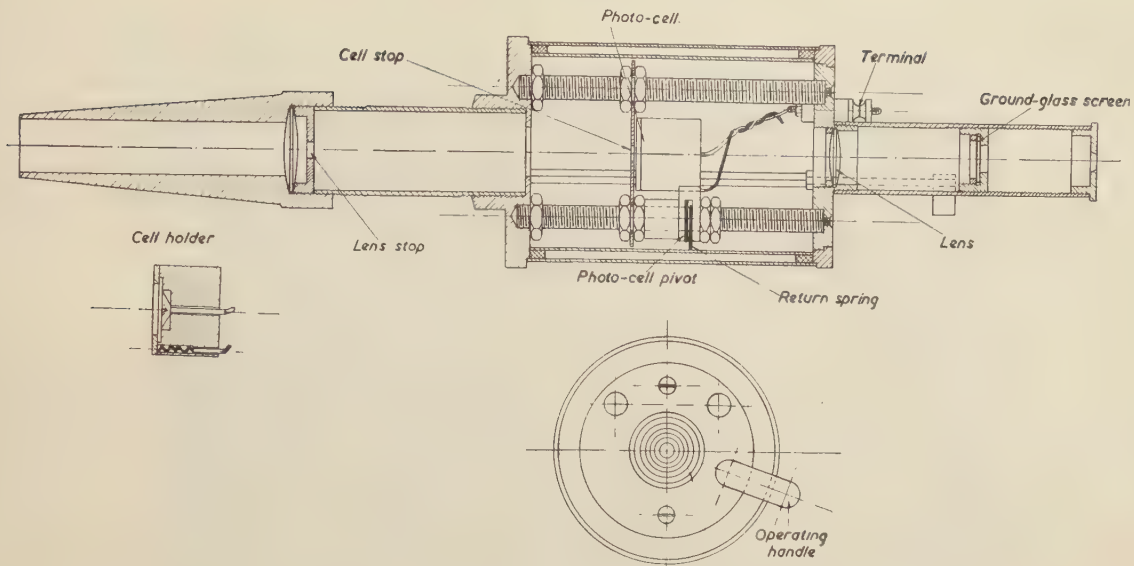


FIG. 1—Constructional details of the pyrometer

pyrometer focuses on the plane of the hot surface of the furnace back wall. This arrangement has the additional advantage that it gives the minimum possible diameter of the incident pencil of rays at this point; the actual diameter required is approximately 5 cm. in this plane.

The pyrometer is shown in detail in Fig. 1, and Fig. 2 illustrates the pyrometer in position in its housing. A water-cooled enclosure surrounds the photo-electric cell and a heat-resisting steel tube, 2 in. in dia., projects in front of this enclosure up to the furnace wall. Compressed air is introduced into this tube and provides an optical path free from smoke and fumes. The rapidly moving air also prevents the entry of hot metallic particles from the furnace, which would otherwise fall on the lens and cause errors of measurement.

The introduction of compressed air was found at first to cause serious trouble owing to the fact

that a fine mist of oil and water was carried forward from the compressor and deposited on the pyrometer lens. Two air filters were fitted in the air line, but the trouble still persisted. The problem was eventually solved by fitting an extension⁷ tube in front of the lens (Fig. 1), which prevented direct contact between the moving air and the lens surface. This arrangement in conjunction with suitable filters has proved entirely satisfactory.

The pyrometer is mounted on a stout girder attached to the buck-stays, immediately above the tap-hole (Fig. 3). The mounting attachment provides for translation of the pyrometer horizontally and vertically, levelling adjustment, and rotation about a vertical axis. In addition, the pyrometer can be swung out of its normal position to facilitate cleaning out the hole in the back wall.

The position of the pyrometer was found to be

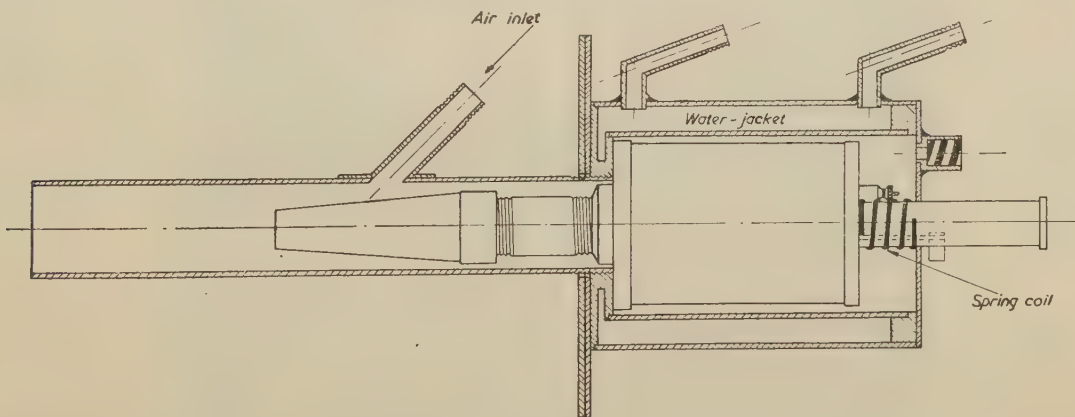


FIG. 2—Assembly of pyrometer in water-jacket

important and if it is placed too low down the wall considerable quantities of sand find their way into the sighting hole during fettling. The best position has been found to be such that there is only one layer of bricks above the sighting hole at the inner surface of the wall. This arrangement has the additional advantage that the flame never comes into the field of view unless the ports are in very bad condition.

The photo-electric cell is connected to a micro-ammeter of 500 ohms internal resistance, giving a full-scale deflection for a current of 15μ amp. (Fig. 4). The meter was calibrated in the laboratory before installation, by sighting on a standard tungsten-ribbon filament lamp. The scale shape of the indicator was based on the author's previous work.³ Since the pyrometer was installed the calibration has been checked at weekly intervals against a disappearing-filament pyrometer, by observation through the sighting hole. The checks have shown no measurable change in calibration over a period of six months. The pyrometer has, during this period, been removed from its housing on one occasion for examination and cleaning, but the lens was found to be in perfect condition and the operation had no effect on the calibration. No adjustments or alterations of the calibration have been made throughout the period, and the only servicing needed has been the removal of accumulated oil and water from the air filters every week by opening a cock for a few minutes.

The melting staff have given the instrument a very favourable reception, and make consistent use of it in operating the furnace. The roof is normally run at about 1650°C ., but when the ports are in need of repair, the roof temperature needed to maintain a normal bath temperature rises to the region of 1680 – 1700°C ., and the meter begins to show an unsteady reading, indicating flame interference.

The remaining source of error is that the sighting hole is occasionally partially obstructed, usually by the melting of the hot surface of the back wall, causing the formation of "stalactites" across the hole. This can, of course, cause serious errors, and if the furnace is to be run to the indication of the pyrometer it is essential that frequent and regular inspection of the sighting hole should be carried out.

PART III—ERRORS OF MEASUREMENT DUE TO THE PRESENCE OF FLAME IN THE FURNACE

It is most important to determine the magnitude of the error introduced into the measurement of the roof temperature by the presence of flame in

the furnace. The pyrometer is calibrated to measure the temperature of a perfect black body, and the furnace with a flame present is clearly not a uniform temperature enclosure. The pyrometer can only be used with confidence if the error is known with fair precision. The problem has been investigated theoretically and experimentally and the results are in satisfactory agreement.

Theoretical Analysis of the Problem

The theoretical approach is based upon the fact that the heat conducted through the roof can be calculated with tolerable precision. Dodd⁸ found that the temperature of the outer surface of a 12-in. thick roof was about 400°C ., so that the average temperature gradient is 100°C./in. Chesters⁹ quotes a value of 10 B.Th.U./sq. ft./hr./ $^{\circ}\text{F./in.}$ for the thermal conductivity of silica brick at 1000°C ., hence the heat flow through the roof is 1000 C.H.U./sq. ft./hr.

A short theorem will now be proved which applies not only to the present case but to any surface in a heated enclosure when the heat flow through that surface is known.

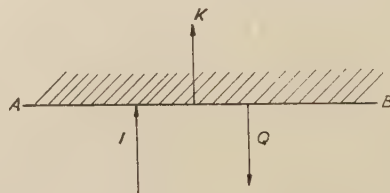


FIG. 5—Heat flow at a surface

Consider a surface AB (Fig. 5) at a temperature T , the total emissivity of which is E , which is heated solely by radiation. Let the incident radiation be I and the heat carried away by conduction be K . Let the radiation leaving the surface be Q ; this consists of two parts, the radiation $(1 - E)I$ reflected at the surface and the radiation $E\sigma T^4$ emitted by the surface.

$$\therefore Q = (1 - E)I + E\sigma T^4 \quad \dots\dots\dots(1)$$

If the temperature of the surface is not changing, we may also write :

$$I = Q + K \quad \dots\dots\dots(2)$$

Eliminating I , we have :

$$Q = (1 - E)(Q + K) + E\sigma T^4$$

$$\therefore Q = \sigma T^4 + \frac{(1 - E)K}{E} \quad \dots\dots\dots(3)$$

If a total-radiation pyrometer is sighted on the

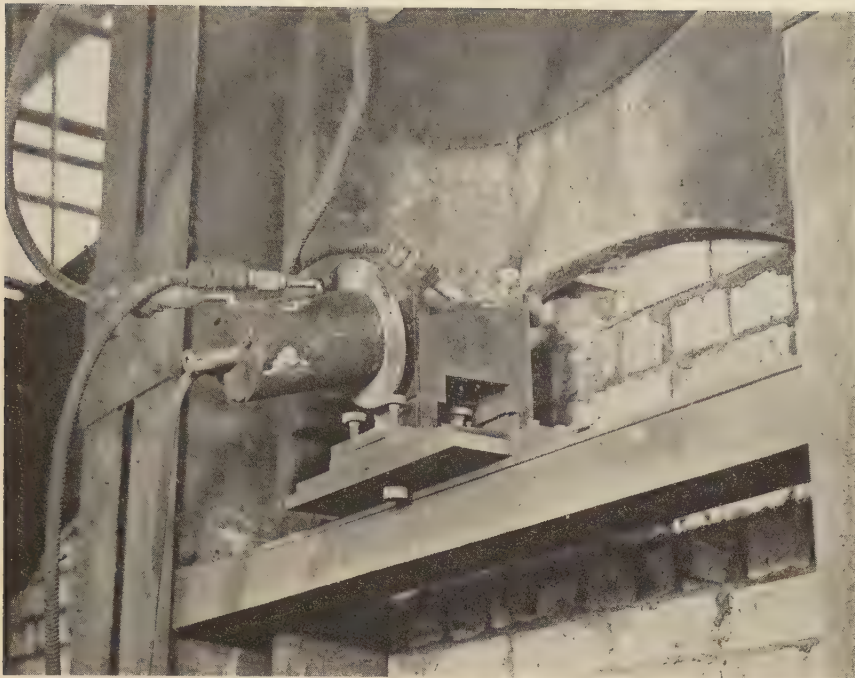


FIG. 3—General view of pyrometer mounted on the back wall above tap hole

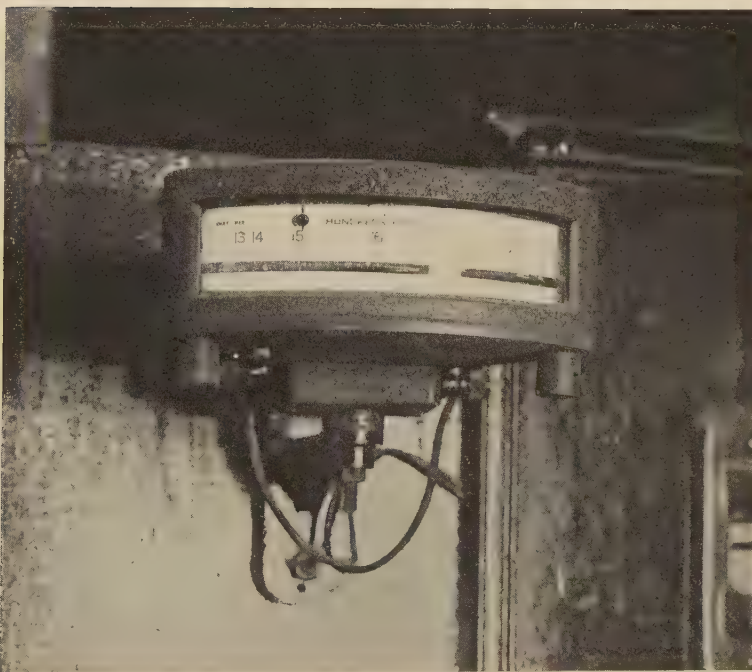


FIG. 4—Temperature indicator

surface, the temperature measured, T_{observed} , is given by :

$$Q = \sigma T_{\text{observed}}^4$$

$$\therefore T_{\text{observed}}^4 - T^4 = \frac{(1-E)K}{E\sigma} \dots\dots(4)$$

This gives the error of measurement, and if the error is small the following may be written :

$$T_{\text{observed}} - T = \frac{(1-E)K}{4E\sigma T^3} \dots\dots\dots(5)$$

If there is heat transfer to the surface by convection of amount C , equation (5) becomes :

$$T_{\text{observed}} - T = \frac{(1-E)(K-C)}{4E\sigma T^3} \dots\dots(5a)$$

We must now consider how far this theorem can be taken to apply to the present case. Since the flame is not in contact with the roof, the gases causing convection at the roof surface will be much cooler and moving much more slowly than those at the slag surface. Baulk and Thring¹⁰ conclude that the heat transfer by convection at the slag surface is likely to be of the order of 1-3% of the heat transfer by radiation. The magnitude of the convective heat transfer by the flame to the slag surface at 1600° C. is deduced from their Table VI to lie in the region of 100-1000 C.H.U./sq. ft./hr. It therefore seems improbable that the convective heat transfer to a roof at, say, 1650° C. will greatly exceed 100 C.H.U./sq. ft./hr. Hence it appears to be satisfactory to ignore convective heating.

Therefore, making use of equation (5) and inserting

$$T = 1923^\circ \text{ K. (1650}^\circ \text{ C.)}$$

$$\sigma = 10.1 \times 10^{-9} \text{ C.H.U./sq. ft./hr./}^\circ \text{K.}^4,$$

we have :

$$\begin{aligned} T_{\text{observed}} - T &= \frac{1000}{4 \times 10.1 \times 10^{-9} \times 1923^3} \times \frac{1-E}{E} \\ &= 3.5 \times \frac{1-E}{E}. \end{aligned}$$

Now, the only data available for the total emissivity of silica at elevated temperatures are values¹¹ of 0.80 at 1000° C. and 0.85 at 1100° C. It seems safe to say that E lies between 0.5 and 1.0 for a silica roof at 1650° C.; thus $(1-E)/E$ lies between 0 and 1.

Hence the error of measurement due to flame in the furnace lies between 0° and + 3½° C. and is probably nearer the lower value. This applies to a pyrometer which responds to the whole of the radiant energy from the roof; both the photo-electric pyrometer and the lens-type radiation pyrometer respond only to certain bands of

wavelengths, and this magnifies the error due to the presence of flame in the furnace.

Equation (1) shows that the radiation received by the pyrometer is partly derived from the roof at temperature T and partly from the flame, walls, and charge. The walls will, on the average, be rather cooler than the roof, the charge will be cooler throughout the melting period, and the flame will always be hotter. Now, as the temperature of a black body increases, the visible radiation increases more rapidly than the total heat emitted. Hence for a given intensity of total radiation a source of heterogeneous temperature emits more light than a source of uniform temperature.

To give a quantitative picture of the magnitude of this effect, suppose that the incident radiation from flame, walls, and charge is composed of one-third from a source at 1550° C., one-third from a source at 1650° C., and one-third from a source at 1750° C. The total radiation will then be equal to that from a source at 1655° C., but the brightness temperature of this mixed radiation, as measured by a photo-electric pyrometer, would be 1669° C., giving a discrepancy of 14° C.

Now, of the radiation from the roof received by the pyrometer, a fraction E emanates from the radiant emission of the roof itself, which will be at a temperature very close to 1655° C.; only a fraction $(1-E)$ of the radiation received by the roof pyrometer is subject to the error which has been discussed. The total error due to flame in the furnace, as measured by a photo-electric pyrometer, for heterogeneous radiation of equal parts from sources at 1550° C., 1650° C., and 1750° C., incident on the roof is as follows :

Emissivity of Roof	Error
0.5	+ 10½° C.
0.8	+ 3° C.
1.0	0° C.

The most probable value of the error is about 2-3° C.

A further complication arises if the flame is not very luminous, as there will then be strong emission and absorption by the flame in the infra-red bands associated with carbon dioxide, water vapour, and probably other molecules and radicals. The effect of this will be to reduce the positive error and under some conditions possibly to introduce a small negative error.

The position may be summarized as follows. For a pyrometer which measures the total radiation at all wavelengths (*i.e.*, a mirror-type instrument with no glass or other material in the optical path), the error introduced by the presence of flame in the furnace would be quite negligible

if it were possible to maintain an optical path from the roof to the pyrometer completely free from carbon dioxide and water vapour. With a photo-electric pyrometer the effect of carbon dioxide and water vapour in the optical path is eliminated and the error of the instrument depends on the degree of heterogeneity of temperature in the furnace. During the refining period, when the slag surface has virtually equalized in temperature with the roof and walls, the error is unlikely to exceed $2-3^{\circ}\text{C}$. When the charge is still cold the error will be greater and may reach as much as $10-20^{\circ}\text{C}$. There are, however, factors such as selective radiation and absorption in the flame which will reduce the magnitude of the error. Furthermore it should be borne in mind that the pyrometer is sighted at a glancing angle to the roof surface so that a degree of specular reflection from the roof and front wall may occur. On balance it seems reasonable to predict that the photo-electric pyrometer will read up to $10-15^{\circ}\text{C}$. high during the melting period. Without an accurate knowledge of the emissivity of silica brick at high temperatures it is impossible to be more precise.

Experimental Investigation

The theoretical treatment outlined in the previous section demands experimental verification. Direct evidence is very difficult to obtain, but it has proved possible to obtain indirect evidence. A stratagem has been employed which depends upon the fact that during reversal the furnace is free from flame for about half a minute, and for that period of time becomes a very satisfactory black-body enclosure. Temperature measurements by radiation methods can therefore be considered fully satisfactory during this period if the charge is fully melted and the slag is heated to approximately the temperature of the roof.

Sosman¹² has pointed out that during reversal the roof temperature as indicated by a radiation pyrometer falls rapidly by between 50° and 100°C . He concluded that this amount represents the error introduced by the presence of the hot flame in the furnace. Dodd⁸ found a temperature drop of the same order of magnitude, but observed that a thermocouple embedded in the roof, $\frac{1}{2}$ in. from the hot surface, showed a fall in temperature of 20°C . during reversal, which indicated that the temperature change was at least partially a real one.

A little consideration makes it clear that there must be a true change in temperature during the reversal period. While the flame is in the furnace,

heat is constantly conducted through the roof and there is a steady temperature gradient from the inside to the outside. When the flame is removed from the furnace, this temperature gradient can no longer be maintained at the hot surface and the heat transfer continues at the expense of the temperature level of the inner surface of the brickwork. The temperature of the hot surface of the roof will therefore fall during the reversal period and the shape of the time-temperature curve during this period can be deduced from the classical theory of heat conduction. The method used in estimating the error due to the flame is to plot the time-temperature curve during reversal and extrapolate this curve back to the instant at which the flame was removed from the furnace. Since the form of the time-temperature curve can be predicted on theoretical grounds, this extrapolation is admissible, and should give an accurate indication of the true temperature of the roof when the flame was still present. A comparison of this value with the indicated value under those conditions gives the error introduced by the presence of the flame.

Theory

In the theoretical treatment of the problem it is assumed that a steady temperature distribution in the furnace roof has been maintained for a few minutes before reversal. It is also assumed that the principle of superposition may legitimately be applied.

Under these conditions the removal of the flame from the furnace at time $t = 0$ is equivalent to the maintenance of the heat input plus the abstraction of an equal amount of heat after time $t = 0$. Since the maintenance of the heat input would maintain a steady temperature, the temperature change after removing the flame is the same as that which would be caused by abstracting a constant amount of heat throughout the period after $t = 0$ from a body initially at a uniform temperature.

For the short period for which the flame is absent from the furnace, it is quite legitimate to consider the roof as a "semi-infinite" solid. For a uniform continuous plane source at the surface of a semi-infinite solid, it can be shown that the surface temperature θ is given by :

$$\theta = -2C\sqrt{\frac{D}{\pi}} \cdot \sqrt{t},$$

where C is equal to the temperature gradient in the roof at the hot surface before reversal and D is the thermal diffusivity of the brick at the operating temperature.

This simple theory is based on the assumption that the flame disappears instantaneously from the furnace. In practice the flame dies away during a period of a few seconds, and the theory must be modified to accommodate this fact.

If the effective flame area is reduced linearly with time during the period between $t = 0$ and $t = \tau$, so that it has completely disappeared at time $t = \tau$, it can be shown that the temperature is given by the real part of the expression :

$$-\frac{4}{3} \frac{C}{\tau} \sqrt{\frac{D}{\pi}} \left\{ t^{\frac{3}{2}} - (t - \tau)^{\frac{3}{2}} \right\}$$

When this expression is plotted graphically it is seen that there is a distinct "knee" in the curve at $t = \tau$, so that it is relatively easy to distinguish the value of τ (Fig. 6).

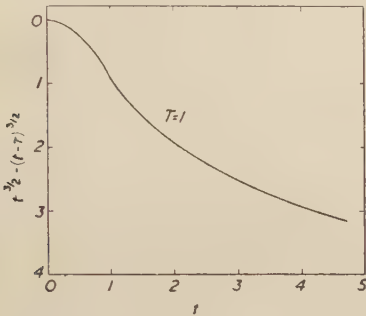


FIG. 6—Theoretical time-temperature curve

It can be shown that the above expression rapidly converges to :

$$-2C \sqrt{\frac{D}{\pi}} \cdot \sqrt{t - \frac{\tau}{2}}$$

with increasing values of t , and is practically indistinguishable from this function for values of t greater than τ (Fig. 7). This fact gives a very convenient method of presenting the results as the time origin need only be placed at time $t = \frac{1}{2}\tau$ after reversal and the temperature plotted against the square root of the time measured from this origin. The experimental results should then fall on a straight line, with the exception of those points close to the origin, and the extrapolation of the line to $t = \frac{1}{2}\tau$ should give the true temperature of the roof before reversal.

It should be noted that the gradient of the straight line relating temperature to the square root of time will have the value $2C\sqrt{D/\pi}$ only if, when the flame is removed from the furnace, there is no heat flow from the roof surface either by convective cooling or by radiation. If either of these types of heat transfer occurs while the

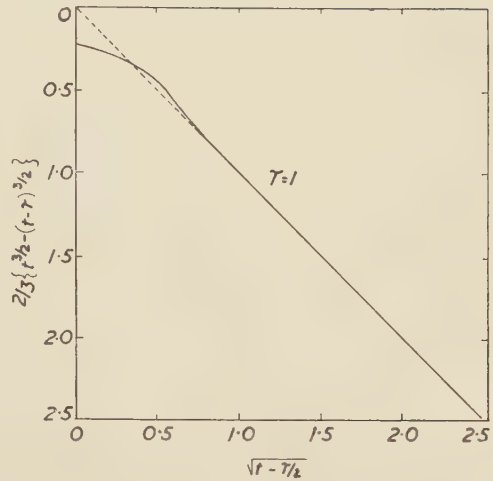


FIG. 7—Theoretical curve for temperature plotted against $\sqrt{t - \frac{\tau}{2}}$

flame is absent, the gradient will exceed the value $2C\sqrt{D/\pi}$, although the line should remain straight, provided that the heat transfer from the surface is independent of time.

Experimental Results

The roof pyrometer for these experiments was connected to a high-speed recording microammeter with a period of about $\frac{1}{4}$ sec. The

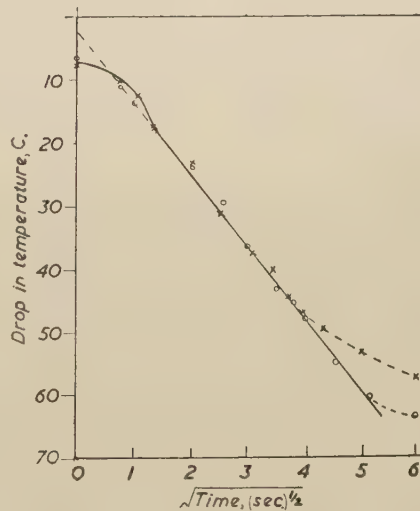


FIG. 8—Drop in temperature of the furnace roof during two different reversals

photo-electric cell has a negligible time lag so that the instrument records the instantaneous temperature without measurable error.

Three reversals were observed, of which two

satisfied the condition of steady roof temperature before reversal. It was found quite easy to detect the "knee" in the time-temperature curve, and so to establish the values of τ . In each case this was found to be 3 sec., and the results of the two satisfactory sets of observations are shown plotted in Fig. 8. The straight line is the best straight line through the experimental points, ignoring those very close to the origin. The slope of this line was measured and the curved part of the line was calculated from the formula:

$$\theta = \frac{2}{3\tau} m \left\{ t^{\frac{3}{2}} - (t - \tau)^{\frac{3}{2}} \right\},$$

where m is the gradient of the straight line. At the bottom of the curve the effect of the flame coming into the furnace can be seen.

Since the thermal constants of silica brick at 1600° C. are not known, it is possible to estimate only very roughly the value of $2C\sqrt{D/\pi}$. A reasonable estimate of the value is 3° C. sec.⁻¹, which is considerably less than the value obtained experimentally for the slope of the line in Fig. 8. It is therefore probable that the roof is cooled by convection or radiation, or both, during reversal.

Discussion

The experimental results are in very satisfactory agreement with theory, and when the straight part of the curve is extrapolated back to the origin of time ($t = \frac{1}{2}\tau$), it is found to cut the temperature axis at a temperature 2° C. below that indicated with the flame in the furnace. Thus the pyrometer reads 2° C. higher than the true temperature of the roof when the flame is in the furnace.

This result is in excellent agreement with the theoretical predictions made in the previous section, and it may be taken that when the slag has reached a temperature of about 1600° C. the error of the pyrometer is quite negligible. There is as yet no experimental evidence of the error due to the presence of the flame when a cold charge is in the furnace.

There are certainly two further tests which could be made in the future. First, a comparison might be made between a photo-electric pyrometer and a total-radiation pyrometer of the mirror type, focused on the same point in the roof. This test would have to be carried out in a part of the furnace known to be free from carbon dioxide and water vapour. With a cold charge in the furnace this would enable the error of the photo-electric pyrometer due to heterogeneity of the incident radiation from charge and flame to

be determined. The experimental difficulties of such a trial would be considerable.

A second investigation might well be made by fitting a suitably sheathed thermocouple in the roof, so that it protruded about 2 in. through the roof at the point where the photo-electric instrument was sighted. If the temperature of the couple is T_c the following may be written:

$$\begin{aligned} \sigma T_c^4 &= \frac{1}{2} (I + Q) \\ &= \sigma T^4 + \left(\frac{1}{E} - \frac{1}{2} \right) (K - C). \end{aligned}$$

Thus the temperature of the couple would exceed that of the roof by an amount less than 5° C. If the couple could be maintained in perfect condition, even throughout the first charge melted in the furnace, it would yield most valuable information.

ACKNOWLEDGMENTS

The author wishes to record his thanks to Mr. D. A. Oliver, Director of Research, Messrs. William Jessop and Sons, Ltd., for his interest in the work, and to members of the Pyrometry Sub-Committee (Chairman, Mr. E. W. Elcock), and of the Open-Hearth Instruments Sub-Committee (Chairman, Mr. F. L. Robertson), of the British Iron and Steel Research Association, with whom the work has been discussed during its progress; also to the Directors of Tinsley Industrial Instruments, Ltd., for help in constructing the instrument to the author's specifications.

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Emissivity of Molten Iron and Steel*

By D. Knowles, A.Met., F.I.M.,† and R. J. Sarjant, D.Sc.†

SYNOPSIS

The emissivity of molten iron and steel has been determined under a wide range of laboratory and workshop conditions. Observations of true temperature were made with immersion thermocouples, and correlated with apparent temperatures indicated by disappearing-filament optical pyrometers. Variations of emissivity were studied in relation to true temperature, the composition of the molten metal, the type of steelmaking process, the character of the lining of either melting furnace or ladle, and the casting conditions. The influence was determined of the content of carbon, silicon, aluminium, chromium, nickel, copper, and manganese. The emissivity of steels melted in acid linings was generally lower than in basic linings. An overriding practical factor was the presence of an oxide film, of which the quantitative effect was determined in a number of instances.

INTRODUCTION

THE object of this paper has been to determine the emissivity of molten steel under a wide range of laboratory and workshop conditions. Until the introduction of the immersion thermocouple, as developed by F. H. Schofield and A. Grace,¹ the disappearing-filament pyrometer had been the main means of determining the temperature of molten steel in melting-shop practice. When the two types of pyrometer came to be used together on the same heats it was clearly realized that the emissivity factor involved in the interpretation of the reading of the optical pyrometer varied widely with variation of shop conditions and with changes in the composition of the steel. It was accordingly anticipated that the combined use of the two instruments might enable a technique to be developed to give additional information on the condition of the steel which is not available when either instrument is used singly.

Further, there are many conditions in foundry practice in which the temperature of the molten steel is required to be known under conditions which preclude the use of the immersion thermocouple. The rapidity with which an optical or similar pyrometer can be used, its portability, and the fact that its use is less liable to interfere with the casting operation are important factors which make it a desirable instrument for such conditions. It becomes necessary therefore that the variables governing the emissivity under workshop conditions should be known, in order that the true temperature of the steel can be derived from the readings obtained by the optical pyrometer.

This examination of the emissivity of molten steel under the varied conditions encountered in foundry practice has reference to the effect of the following major factors :

- (i) The true temperature.
- (ii) The composition of the molten metal.
- (iii) The type of steelmaking process.
- (iv) The character of the lining of the container—either melting furnace or ladle.
- (v) The casting conditions.

All the above factors have been found to have a more or less significant bearing upon the emissivity observed.

SCOPE OF THE INVESTIGATIONS

The data incorporated in this survey were chiefly obtained from three main investigations :

(a) Experiments made with a laboratory 20-lb. high-frequency furnace having a sillimanite crucible as container. The general technique was to explore the emissivity over a temperature range by pouring successive portions of the heat after various steady temperatures had been attained.

* Paper No. 22/1947, submitted by the Foundry Steel Temperature Sub-Committee of the Steel Castings Research Committee, received 27th August, 1946. The views expressed in the paper are the authors' and are not necessarily endorsed by the Sub-Committee as a body.

The Foundry Steel Temperature Sub-Committee of the Iron and Steel Institute was reconstituted with the Liquid Steel Temperature Sub-Committee in April, 1946, to form the Pyrometry Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association.

† Messrs. Hadfields, Ltd., Sheffield.

The true temperature was determined by means of immersion couples and the apparent temperature by optical readings taken on the pouring stream as it passed over the lip of the crucible. Corrections were made for the time interval occurring between the two observations.

(b) Data obtained from heats melted in a works 2-cwt. high-frequency furnace using both acid and basic monolithic linings. The true and apparent temperatures were taken both in the furnace and in the shank (small ladle) used for the subsequent casting operations. Although both acid and basic linings were used in the furnace, the shank lining was always acid. In the case of basic heats, therefore, observations were obtained when pouring from a basic-lined furnace into the shank and subsequently from the acid-lined shank into the mould. From the close agreement of emissivity obtained with both the pouring and the casting observations it was evident that the time the metal was held in the acid shank (approximately $\frac{3}{4}$ min.) was too short for any appreciable change of emissivity to occur. Full corrections were made for the influence of the time factor.

(c) Observations made under foundry conditions. In these observations those variables of shop practice have been included which are believed to have a pertinent bearing on the results. It was not generally practicable to make accurate corrections for the influence of the time elapsing between the reading of the immersion couple and that of the optical pyrometer. In every case the optical reading was obtained on the surface of the metal as it was poured over the lip of the furnace, ladle, or shank.

The observations covered the following types of steels :

(a) *Laboratory High-Frequency Furnace—Sillimanite Lining*

- (1) Armco and cut iron.
- (2) Plain carbon steels and irons.
- (3) Effect of small additions of aluminium, silicon, and manganese to a plain carbon steel.
- (4) $1\frac{3}{4}\%$ copper steel.
- (5) 13% manganese steel.
- (6) High-alloy steel (18% Cr, 9% Cu).
- (7) High-alloy steel (12% Cr, 35% Ni).
- (8) High-alloy steel (25% Cr, 18% Ni).

(b) *2-cwt. High-Frequency Furnace—Acid and Basic Linings*

- (1) Plain carbon steel.
- (2) $1\frac{3}{4}\%$ copper steel.
- (3) $3\frac{1}{2}\%$ nickel steel.
- (4) 13% manganese steel.

(c) *Foundry Observations*

- (1) Plain carbon steel.
- (2) $1\frac{3}{4}\%$ copper steel.
- (3) High-chromium steel (29%).
- (4) High-chromium-nickel steel (25% Cr, 18% Ni).

- (5) Nickel-chromium steel (12% Cr, 35% Ni).
- (6) Cupola metal.
- (7) Blown iron from converters.

Many other classes of steel have been examined, but only those have been included in this analysis in which the effects of specific factors could be identified.

APPARATUS

The immersion couples used were chiefly of the standard portable type, using platinum/platinum-13% rhodium wires, 0.5 mm. in dia., with silica sheaths 12 cm. long of 7 mm. external dia. and $5\frac{1}{2}$ mm. bore. The tips were held in the pyrometer tube by metal chucks. The measuring instruments consisted of potentiometers and Tinsley D.C. amplifiers having an accuracy of the order of $\pm 5^\circ \text{C}$.

The calibration of the thermocouple wires was checked against the freezing points of the usual low-temperature standards, of gold, and the melting points of palladium and platinum for the higher temperature ranges.

The disappearing-filament optical pyrometers used were chiefly of two types, having the following characteristics :

No. 1—Potentiometric type of wavelength 0.655μ , having a flat filament 0.04 mm. wide and a very open temperature scale. This instrument was used for all the observations taken on the 2-cwt. high-frequency-furnace heats and for certain other miscellaneous readings. The accuracy of the scale reading was of the order of $\pm 3^\circ \text{C}$.

No. 2—Millivoltmeter type, of wavelength 0.648μ , with a circular filament of 0.04 mm. dia. This type was used for the majority of the foundry heats and had an estimated accuracy of $\pm 10^\circ \text{C}$. under good sighting conditions.

ANALYSIS OF DATA OBTAINED

The data have been analysed in the following manner. The true temperature as measured by means of the immersion thermocouple has been plotted for every set of observations against the apparent brightness temperature indicated by the disappearing-filament pyrometer. The curve drawn through the points has in every case been derived by the method of least squares, assuming the true temperature to be the independent variable. From this curve the relation between true temperature and emissivity, which is shown in the second part of the diagrams, has been derived. In certain cases a third part has been added showing the relationship of the three factors, apparent temperature, correction necessary for conversion to true temperature, and emissivity.* The

* See Appendix I.

values of the emissivity may be read by interpolation between the lines of equal emissivity, which are drawn on the diagrams. In the interpretation of the results shown it must be borne in mind that a 10° C. error in the observation of apparent temperature is equivalent to a difference of approximately 0.03 in the emissivity coefficient. This leads to exaggeration of the random errors introduced by such influences as the personal factor of the observer in matching up the filament, the accuracy with which the instrument scale can be read, the presence of fume, and the shape of the molten stream. Accordingly, the course adopted in the two upper portions of the diagrams has the effect of averaging these variables in each separate set of results, and to some extent of eliminating them.

A survey of each particular series of experiments shows the following salient features.

Heats Made in the 20-lb. Laboratory High-Frequency Furnace—Sillimanite Pot

Figure 1: Armco and Cut Iron

The emissivity factor is shown to be of the order of 0.4, and it rises slightly with increasing temperature. For comparison purposes the curve given by Bidwell² for liquid iron is included. As long ago as 1917, G. K. Burgess³ observed the

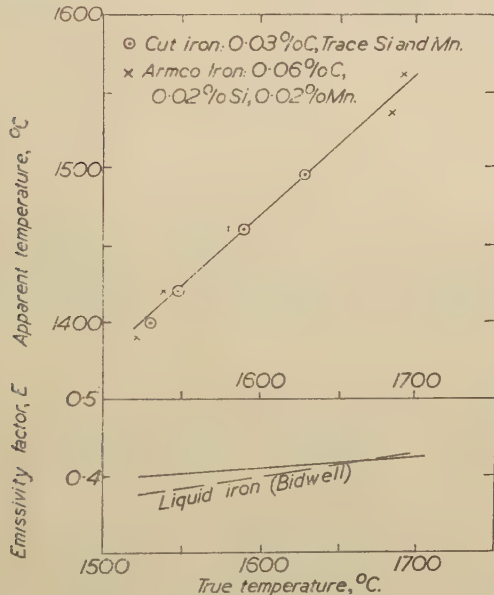


FIG. 1—Molten iron, experimental high-frequency furnace (20 lb.), sillimanite lining

emissivity of a smooth surface of liquid iron free from oxide to be 0.37 for a wavelength of 0.65μ, using a Holborn-Kurlbaum form of Morse pyrometer. The standard of accuracy of the optical pyrometer used was stated to be 5° C. at 1,500° C. For practical use Burgess adopted a standard of

0.40 for the emissivity factor in converting to the true temperature the apparent temperatures observed by means of the optical pyrometer. His reasons were based on what he described as "a slight evanescent surface of oxide, giving to the stream viewed through red glass a characteristic transparent appearance, the colour of the metal being greenish and that of the oxide yellow." It is interesting to note the confirmation of Burgess' original values.

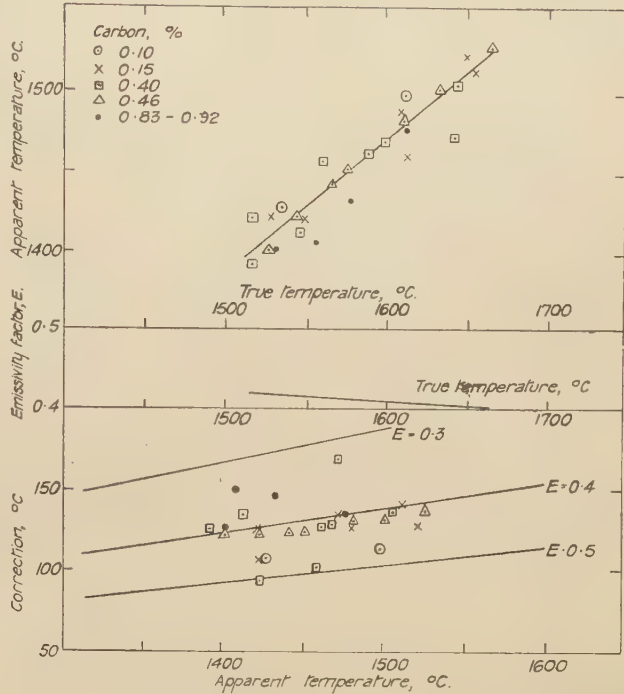


FIG. 2—Plain carbon steels. Experimental high-frequency furnace (20 lb.), sillimanite lining

Figure 2: Plain Carbon Steels Containing up to 1.0% of Carbon

Within these limits the addition of carbon has little effect on the emissivity, which falls with increasing temperature. There are slight indications from the position of the four observations made on the 0.92-0.83% carbon steels that the emissivity of hypereutectic steel is less than that of hypo-eutectic steel.

Figure 3: 1.8% and 3.5% Carbon Steels

In this case a mean curve has been drawn through all the observations, for although slight differences are apparent between the two types of steel, the deviations are within the limits of experimental error. Comparing the results with those of Fig. 2 it is evident that the higher content of carbon lowers only very slightly the value of the emissivity.

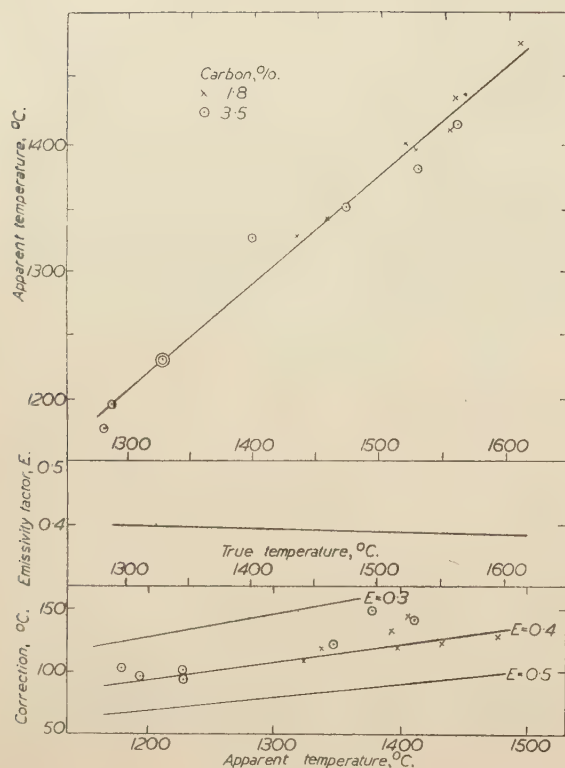


FIG. 3—1.8% and 3.5% Carbon steels. Experimental high-frequency furnace (20 lb.), sillimanite lining

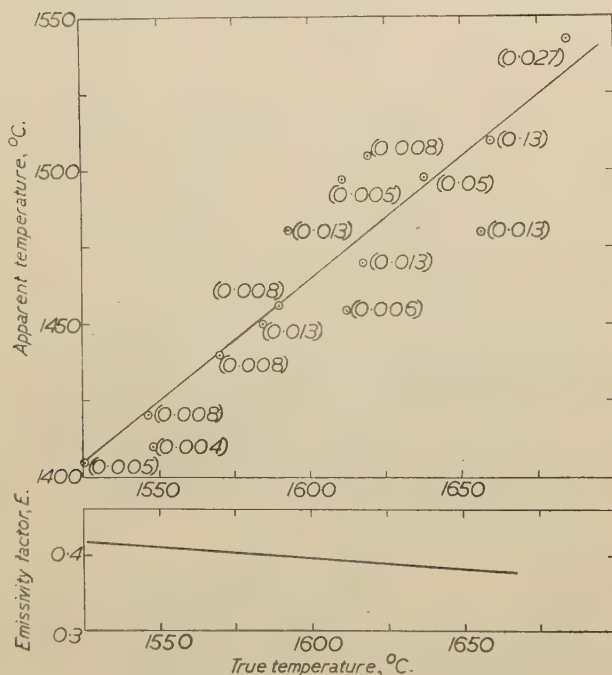


FIG. 4—Effect of small additions of aluminium on the emissivity of plain carbon steel (0.15% carbon). Experimental high-frequency furnace (20 lb.), sillimanite lining. Figures in parenthesis denote the percentage of aluminium found in the cast steel

Figure 4 : Effect of Small Additions of Aluminium
(Based on the Residual Aluminium Content)

These observations are very conflicting and do not show any decisive effect of the residual aluminium content of the steel. In all these heats considerably more aluminium was added to the melt than that actually found in the final steel, and it seems evident that the varied contents of aluminium can be ascribed to the oxidation of the deoxidant. A mean curve correlating the emissivity factor E with true temperature is shown in the lower section of Fig. 4 and indicates a result similar to those obtained with plain carbon steels. (Cf. Fig. 2.)

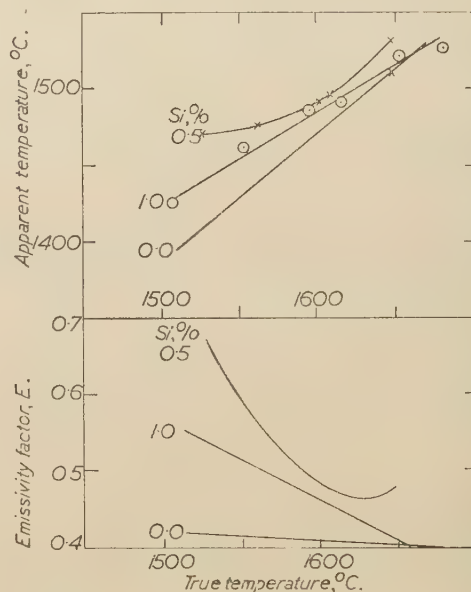


FIG. 5—Effect of small additions of silicon on the emissivity of plain carbon steel (0.15% carbon). Experimental high-frequency furnace (20 lb.), sillimanite lining

Figure 5 : Effect of Silicon Additions

These curves indicate that at low temperatures silicon tends to increase the emissivity factor of a plain carbon steel, but the effect is not proportional to the amount added. These results are not in accord with other published data (Guthmann⁴ and Goller⁵), thus suggesting that silicon tends to lower the emissivity of steel because of its tendency to remove any oxide film.

Figure 6 : Effect of Manganese Additions

Up to 1.0% of manganese has little effect on the emissivity and such variations as exist are within the limits of experimental error.

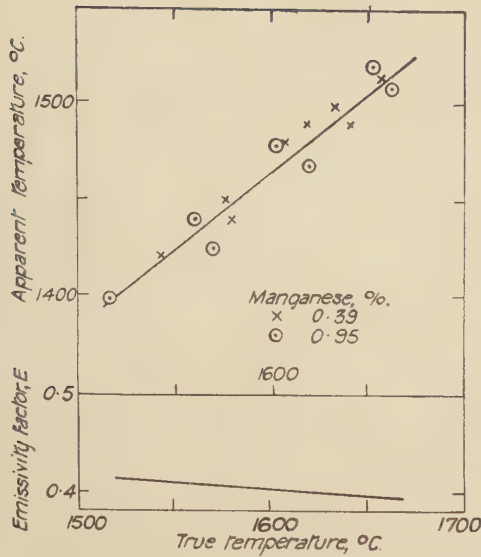


FIG. 6—Effect of small additions of manganese on the emissivity of plain carbon steel (0.15% carbon). Experimental high-frequency furnace (20 lb.), sillimanite lining

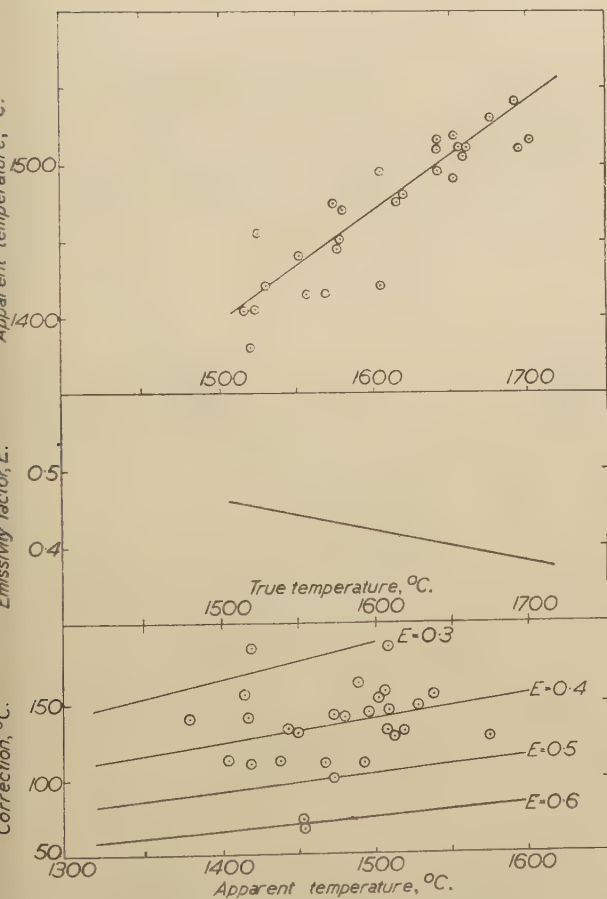


FIG. 7—1.75% Copper steel. Experimental high-frequency furnace 20 lb.), sillimanite lining

Figure 7 : 1 $\frac{3}{4}$ % Copper Steel

The presence of copper has a tendency to raise the emissivity factor at low temperatures (cf. Fig. 2), but the effect is slight and again within the limits of error. Scum formation is prevalent with this steel and has a pronounced effect on the emissivity; it will be noted that owing to these conditions the scatter of the points in the relation of apparent temperature against true temperature is more marked than with certain other steels.

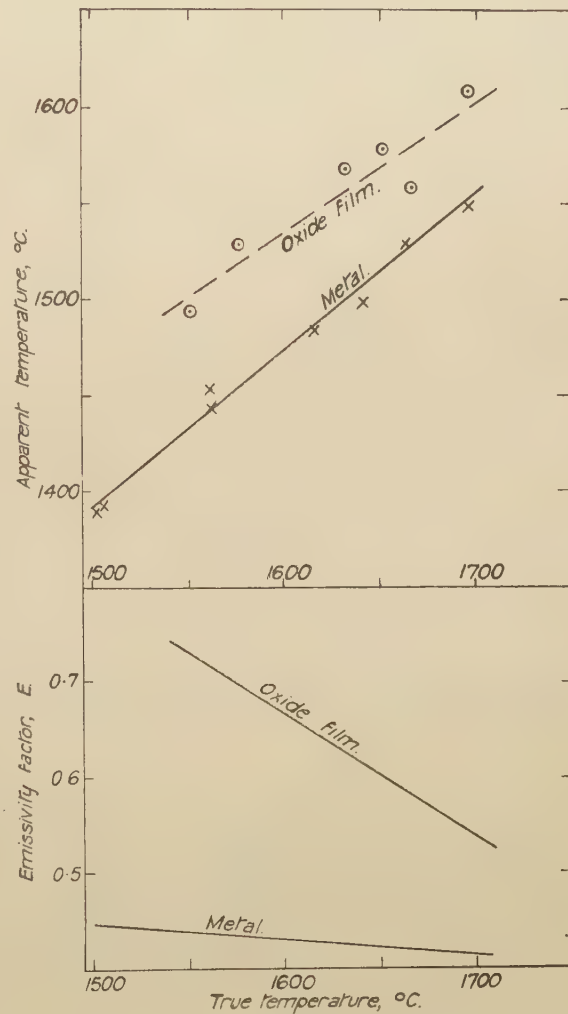


FIG. 8—18% Chromium, 9% copper steel. Experimental high-frequency furnace (20 lb.), sillimanite lining

Figure 8 : 18% Chromium, 9% Copper Steel

The alloy additions increase appreciably the emissivity of the molten steel. This steel is also prone to scum formation, and observations made on the scum in the furnace are incorporated in the

diagram. There is a marked increase in emissivity when sighting on the scum, but this emissivity decreases with increasing temperature.

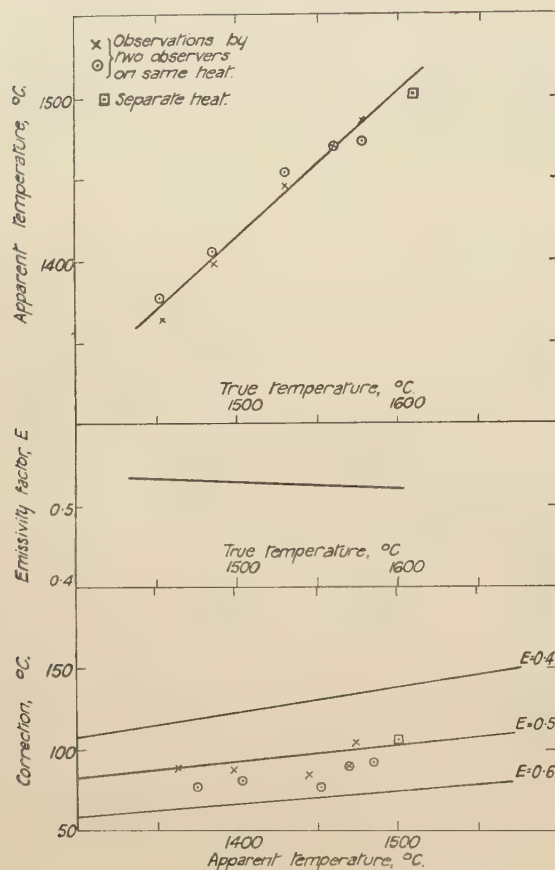


FIG. 9—12% Chromium, 35% nickel steel. Experimental high-frequency furnace (20 lb.), sillimanite lining

Figure 9 : 12% Chromium, 35% Nickel Steel

The effect of the alloy additions is to increase to a marked degree the emissivity of the molten metal, the increase being appreciably greater than that which would be expected from the results obtained with steel containing 9% of copper and 18% of chromium (Fig. 8).

Figure 10 : 25% Chromium, 18% Nickel Steel, and 29% Chromium Steel

The curves of these two steels are practically identical and have therefore been combined. The relationship between emissivity and true temperature is outstanding in that there is a decided increase of emissivity with rising temperature.

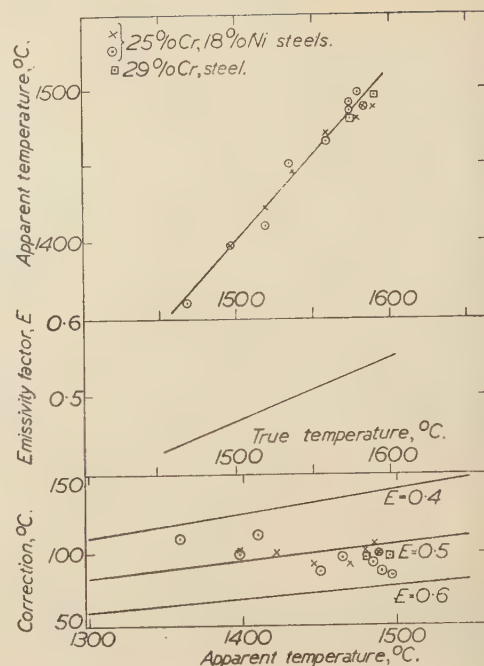


FIG. 10—25% Chromium, 18% nickel steel; and 29% chromium steel. Experimental high-frequency furnace (20 lb.), sillimanite lining

Heats Made on a 2-cwt. High-Frequency Furnace (Acid and Basic Linings)

Figures 11 to 14 : Miscellaneous Steels

The chief feature of these observations is that in every case the steels made in acid linings have a lower emissivity than similar steels made in basic

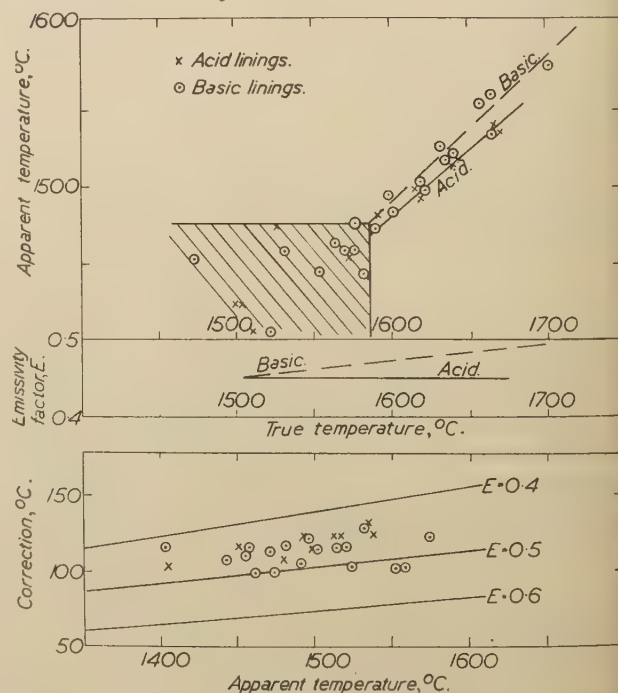


FIG. 11—Plain carbon steel (0.30% carbon); 2-cwt. high-frequency furnace

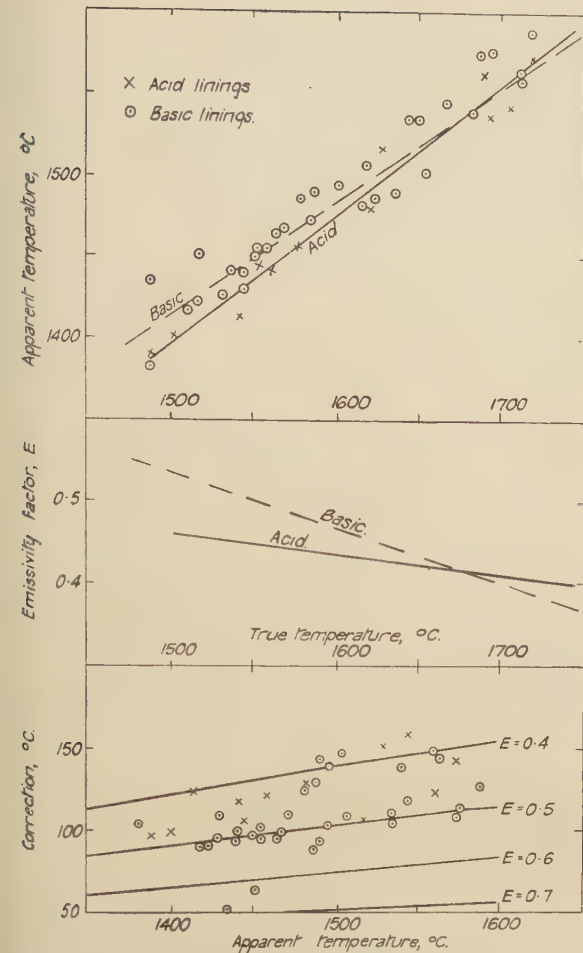


FIG. 12—3.5% Nickel steels. High-frequency furnace (2 cwt.)

linings. In addition, it will be noticed by comparing Figs. 11 and 2, and 13 and 7, that the larger furnace gave a higher emissivity than the smaller 20-lb. furnace for the same class of steel. Incorporated in Fig. 14 are three observations made on a similar 13% manganese steel melted in the small experimental furnace which show the same effect. As regards the plain carbon steel (Fig. 11) made in a basic lining, a peculiar change of emissivity, and incidentally of fluidity also, was noticed in the region of 1575°C . (true), for which no satisfactory explanation can as yet be given. In view of this uncertainty this portion of the diagram has been cross-hatched. The silicon content of the metal used for these observations (basic heat) was exceptionally low so that the state of oxidation is presumably the cause. A similar effect has been noticed with $1\frac{3}{4}\%$ copper steel made in the 20-lb. high-frequency furnace, but unfortunately the silicon content was not determined. At the time of the observations the increase of

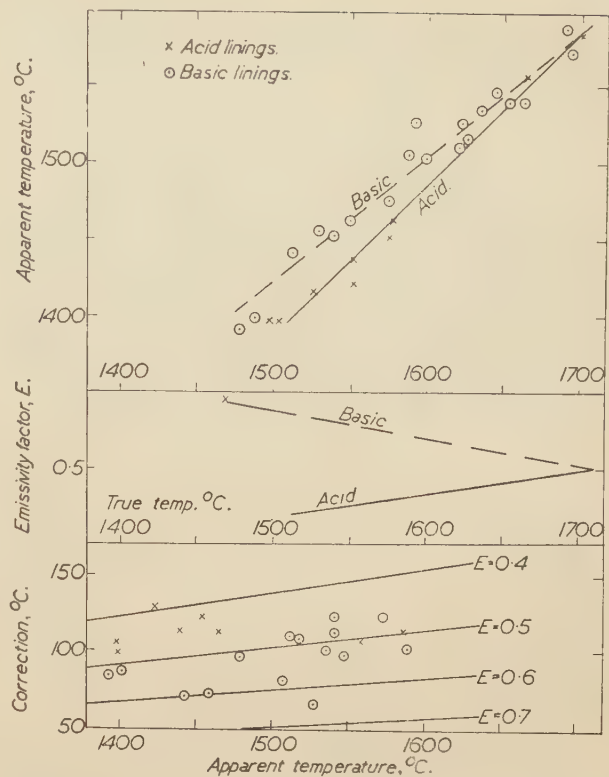


FIG. 13—1.75% Copper steel. High-frequency furnace (2 cwt.)

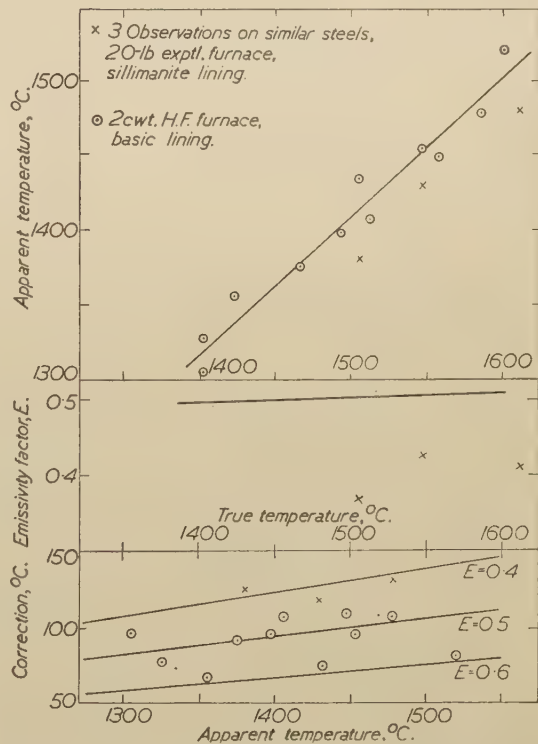


FIG. 14—13% Manganese steel. High-frequency furnace (2 cwt.)

emissivity was ascribed to oxide film, although no film as distinct from metal was discerned by the observer using the optical pyrometer.

Foundry Observations

Figures 15 to 19 : Miscellaneous Steels

As mentioned above, considerable scatter of the plotted observations obtained under foundry conditions persists, and therefore only typical curves have been selected. Comparing Figs. 15 and 2, 16 and 7, and 17 and 10, the data being collected in Fig. 25, all the curves obtained from the larger high-frequency furnaces show a

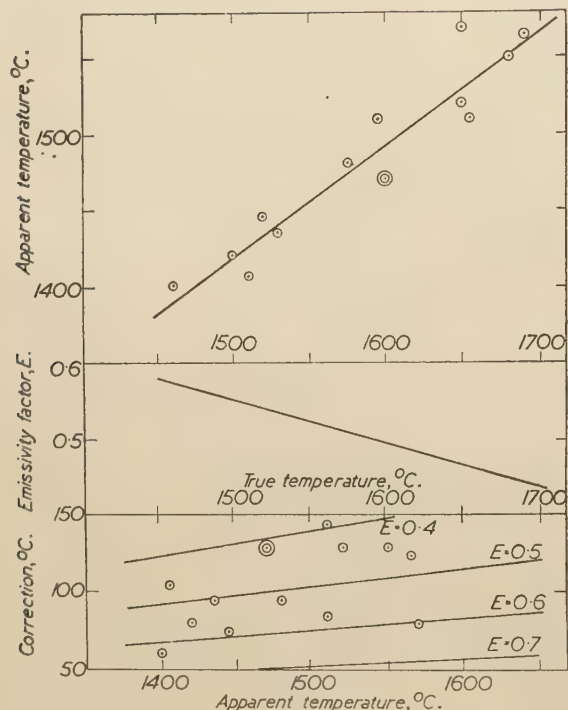


FIG. 15—Plain carbon steel. Foundry high-frequency furnaces ($\frac{1}{4}$ –2 tons), acid and basic linings

decidedly higher emissivity than those obtained from the smaller furnaces under laboratory conditions. The differences cannot be attributed to variations of composition; they may be due in the larger furnaces to the existence of an oxide film. The results given in Fig. 18, derived from observations on a high-nickel-chromium steel melted in an electric-arc furnace, are of particular interest. Before the adoption of the immersion-couple technique of temperature measurement, the optical pyrometer had been used as a control instrument for this class of steel. It was observed that any fall of furnace temperature below approximately 1550° C. true (1490° C. apparent) was not reflected in the optical reading. The

reason became apparent when true temperatures were available. Below 1550° C. the scum is very persistent and accordingly the emissivity factor shows a proportionate increase with falling temperature, reaching a value of practically 1.0 at 1470° C. Hence a drop of approximately 80° C. in the true temperature gave a corresponding

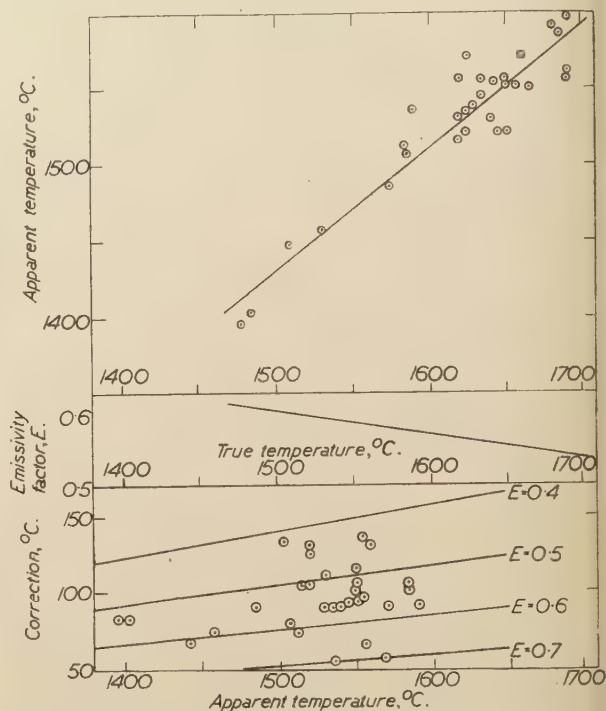


FIG. 16—1.75% Copper steel. Foundry high-frequency furnaces ($\frac{1}{4}$ –1 ton), acid and basic linings

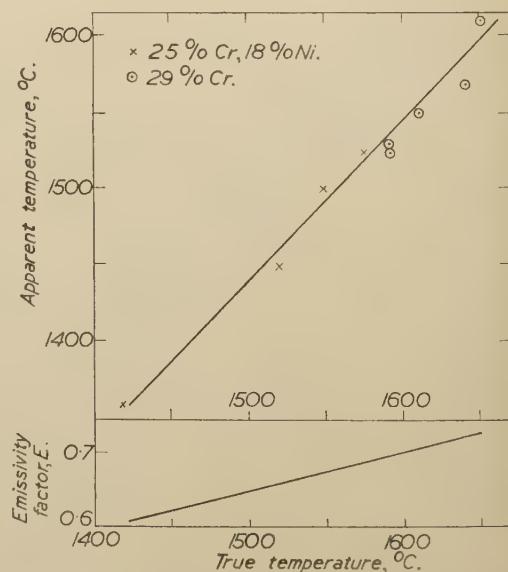


FIG. 17—High-chromium steels. Foundry high-frequency furnaces ($\frac{1}{4}$ –1 ton), acid and basic linings

drop of only 20° C. in the optical reading. W. J. Todd⁶ had noted a similar close agreement between brightness and true temperature for both chromium-nickel and chromium-copper steels.

As regards the data given in Figs. 19 and 20, both cupola metal and blown iron show an increase of emissivity with increasing temperature, which is the reverse of what occurs with 3.5% carbon steel and Armco iron made in the 20-lb. high-frequency furnace (Figs. 3 and 1). This again infers the presence of an oxide film which in these cases is the more pronounced the higher the temperature.

DISCUSSION OF RESULTS

The results obtained have been considered in the light of other published data.

Effect of Temperature

Previous data have indicated, in general, that the emissivity of molten steels falls with increasing

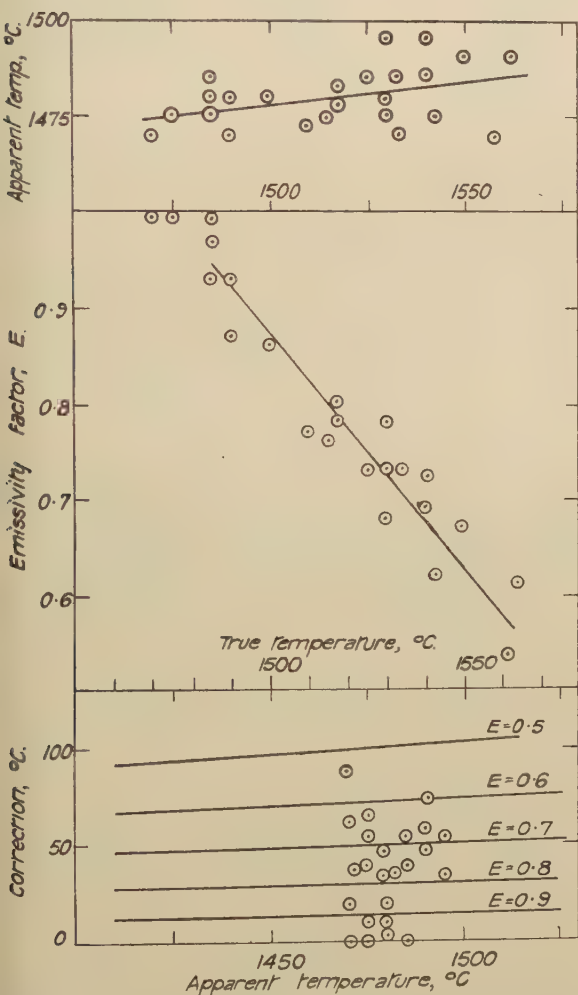


FIG. 18—12% Chromium, 35% nickel steel. Electric-arc furnace, basic lining

temperature. The authors' observations have shown that this applies only in the case of plain carbon steels, irons, and low-alloy steels. In high-alloy steels, blown iron, and cupola metal, the reverse effect occurs.

The results of the present investigation are in agreement with those of Guthmann,⁴ Naeser,⁷ Spencer,⁸ and Hase,⁹ in regard to the relation between emissivity and temperature for carbon steels. Goller⁵ has found a rise of emissivity with increasing temperature for such steels, but the results applied to the conditions in a small, basic-lined high-frequency furnace. (Cf. Fig. 21.)

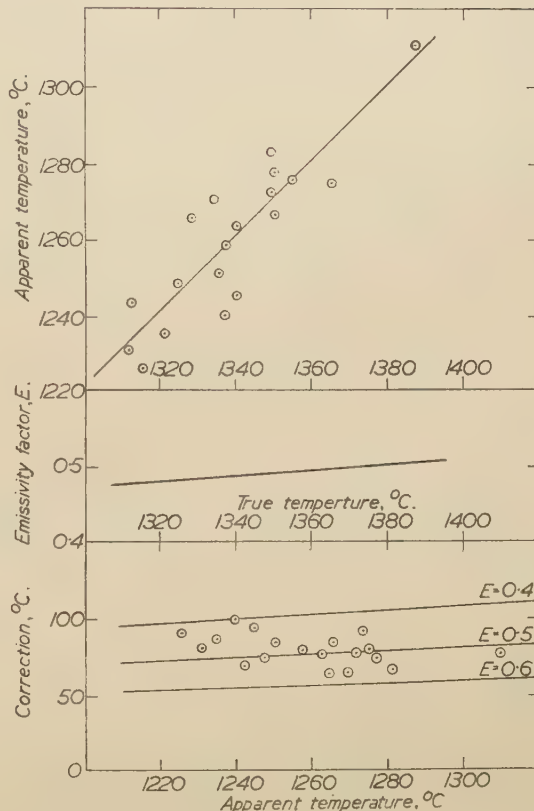


FIG. 19—Cupola metal. Composition: 3.5-3.7% of carbon, 1.1% of silicon, 0.8% of manganese

As regards high-alloy steels, however, particularly chromium steels, the emissivity increases with temperature. The curves of Goller⁵ and of Gow¹⁰ and his co-workers also show this effect, but it is a general experience that these types of alloys develop a surface scum which makes accurate optical measurement of the temperature of the true metal uncertain. Such oxide films increase the apparent emissivity of the metal and the intensity of the effect is dependent on the nature of the film, which in turn is governed by the composition, the condition of casting, and the temperature. As the last-named factor rises, the

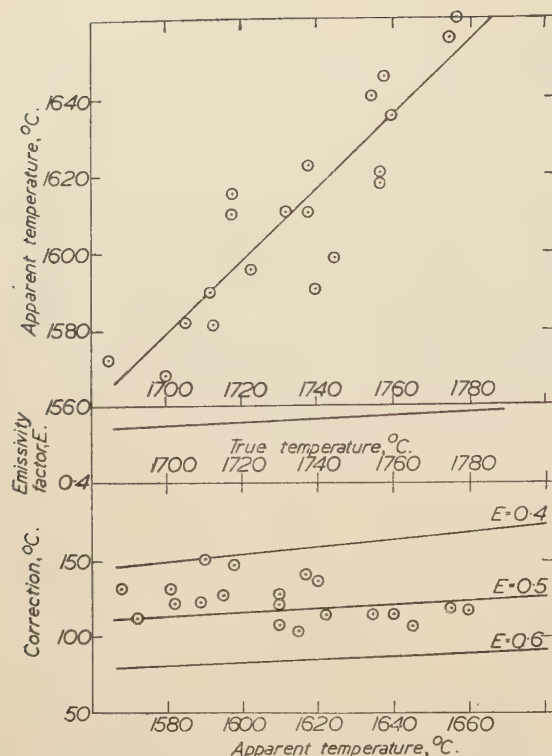


FIG. 20—Blown iron (acid process). Composition : 0.6% of carbon, 0.03% of silicon, 0.03% of manganese

oxidation of easily oxidizable elements becomes more pronounced, so that at relatively high temperatures it is conceivable that the surface may never be clear of oxide film. (Cf. Fig. 22.)

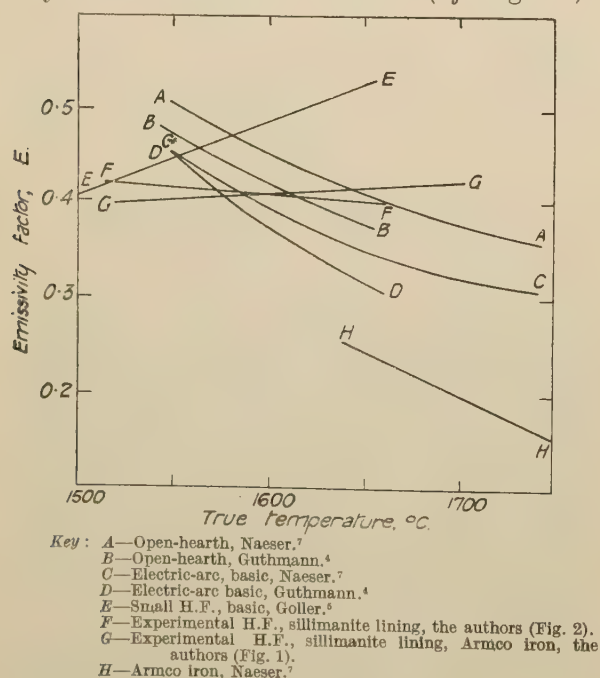


FIG. 21—Comparison of observations of emissivity of carbon steel by different investigators

Effect of the Composition of the Steel

It would be anticipated that of all the factors affecting the emissivity of liquid ferrous metals, that of composition could be established fairly accurately. Unfortunately this is not the case, and examination of the literature shows serious differences in the emissivity coefficients quoted for such simple metals as plain carbon steels and Armco iron (Fig. 21). Under such circumstances no basic curves are available for use as standards from which to determine any quantitative or numerical values for the effect of various alloy additions, and it is only possible to indicate the trend of emissivity which such alloy additions may have. The matter requires detailed examination under standard conditions.

Most investigators substantially agree as regards the following effects of alloy additions on the emissivity factor (E) of molten ferrous metals :

Elements which Increase E	Elements which Decrease E	Elements which have no Effect
Copper	Aluminium	Carbon
Chromium	Silicon	Molybdenum
Manganese	Sulphur	
Titanium		
Tungsten		

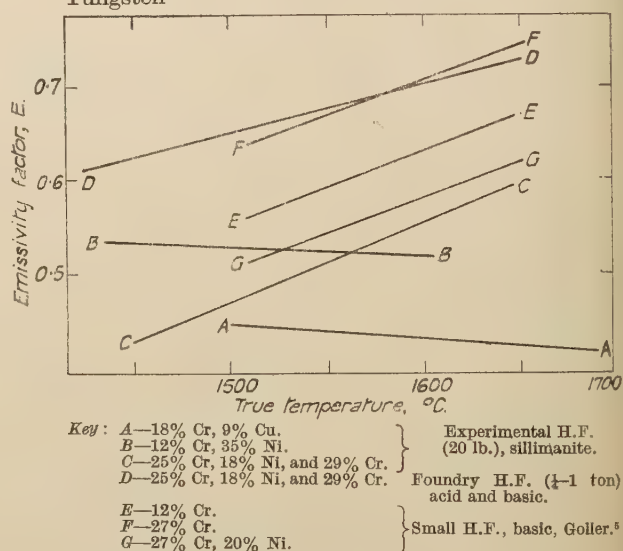


FIG. 22—Emissivity of high-alloy steels

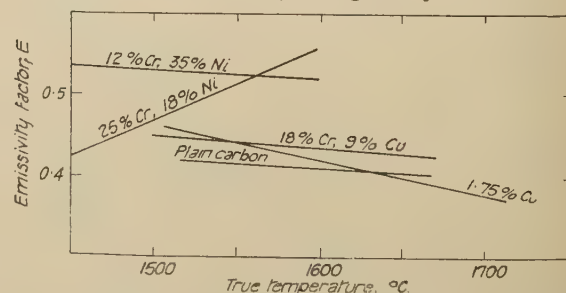


FIG. 23—Effect of chromium, nickel, and copper additions. Experimental high-frequency furnace (20 lb.), sillimanite lining

Carbon

Below the eutectic composition, varying carbon content does not affect emissivity (Fig. 2), but above the eutectic composition the emissivity is lowered by increasing carbon content (*cf.* Figs. 2 and 3).

Silicon and Aluminium

Naeser⁷ does not agree with Goller⁵ and Guthmann⁴ as regards the decreasing effect of silicon and aluminium, and he maintains that the effect is only temporary, as both deoxidants speedily burn out and "the resultant inclusions may increase the emissivity." Figures 4 and 5 obtained in the present study tend to verify his observations. With both deoxidants the results are erratic, and Naeser's claim, that there is an optimum amount of silicon and aluminium depending on conditions which give the lowest emissivity coefficient, seems reasonable.

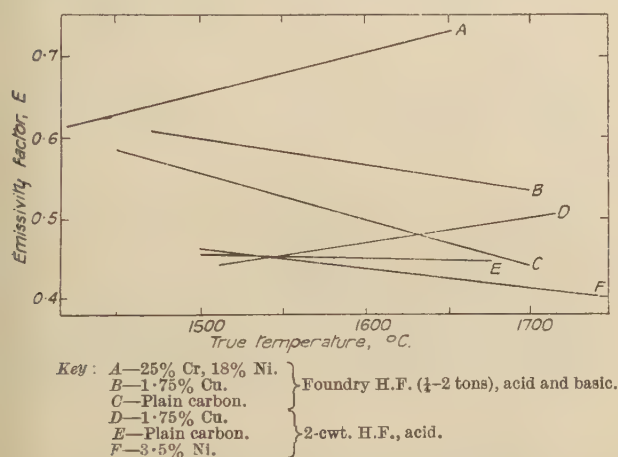


FIG. 24—Emissivity of high-alloy steels

Chromium

It is generally recognized that chromium additions increase the emissivity of steel, and the present work verifies the generalization (Figs. 23 and 24).

Nickel

Guthmann⁴ states that nickel additions do not affect emissivity, but Goller,⁵ in his work on stainless steels melted in a basic-lined laboratory high-frequency furnace, found that it had a decreasing effect, practically the reverse effect of chromium for the same percentage additions.

The data obtained in these investigations are not conclusive as regards the effect of nickel additions, but according to Figs. 10, 11, and 12 it would appear that they have little effect on the emissivity of molten steel or, possibly, a diminishing effect at high temperatures above 1600° C. (true).

Copper

Comparing Figs. 2 and 7, which are also incorporated in Fig. 23, it will be seen that 1.75% of copper has little effect on melts made in a small high-frequency furnace, but with larger furnaces (Figs. 11, 13, 15, and 16) the emissivity increases at high temperatures and the larger the furnace the greater the increase. The corresponding curves for acid steels are shown as curves E, D, C, and B, in Fig. 24.

Effect of the Method of Manufacture

The method of manufacture can appreciably affect the emissivity of molten steel of the same chemical composition. The results shown in Fig. 25, covering high-frequency melting only, indicate the decided influence of the size of the furnace on the emissivity; the larger the furnace the higher the emissivity.

The curves in Fig. 26, reproduced from Figs. 9 and 18, show the difference obtained with a high-chromium-nickel steel melted in a small high-frequency furnace (20 lb.) and in large electric-arc

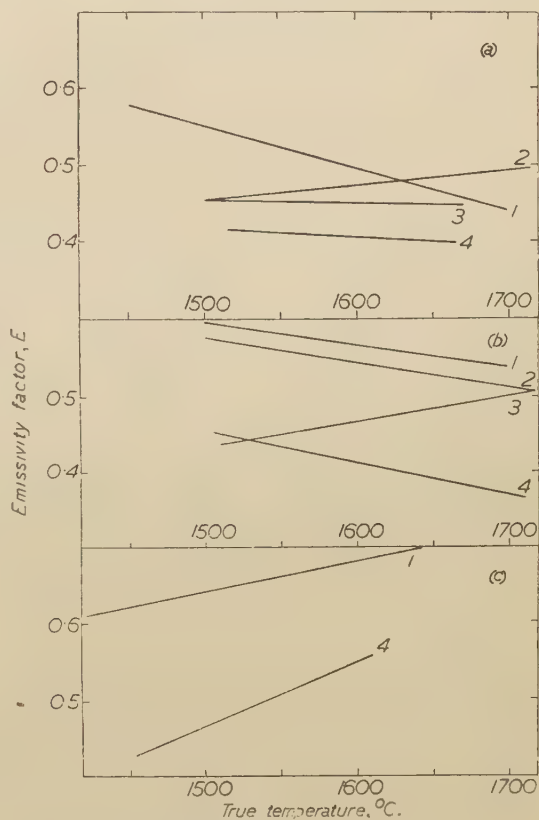
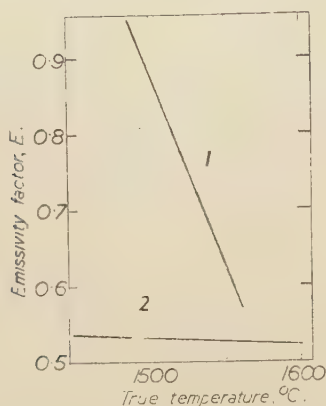


FIG. 25—Effect of the method of manufacture. High-frequency furnaces of various sizes. (a) Plain carbon steel, (b) 1.75% copper steel, and (c) 25% chromium, 18% nickel steel

furnaces (6–15 tons). This steel develops a persistent oxide scum which in the case of the high-frequency melt is held back by a pot of narrow diameter and enables the true metal surface to be seen and its temperature measured by the optical pyrometer during the pouring operation. In the case of the electric-arc furnaces the tapping stream is appreciably affected by the oxide film.



Key: 1—Electric-arc furnaces (6–15 tons).
2—Experimental furnace (20 lb.), sillimanite lining.

FIG. 26—Effect of the method of manufacture on the emissivity of 12% chromium, 35% nickel steel. Comparison of the electric-arc (basic) and experimental high-frequency (sillimanite lining) processes

For open-hearth and electric-furnace heats, Guthmann⁴ and Naeser⁷ give curves, reproduced in Fig. 27, showing the higher emissivity of open-hearth plain carbon steel as against electric-furnace steel. It will be noticed that the two sets of curves do not agree amongst themselves, again indicating the difficulty of establishing any standard base curves for reference and the interfering effect of the possible presence of slag or scum on the surface observed. Guthmann⁴ also found that the larger the furnace, the higher the emissivity for the same class of steel. This may be again a question of scum and slag.

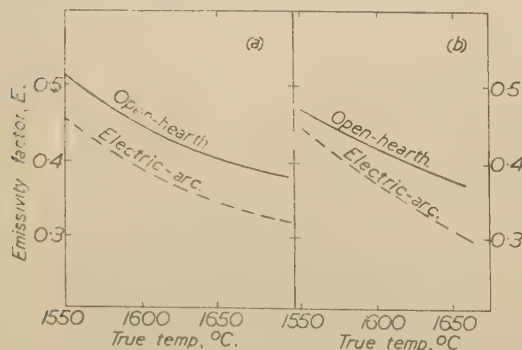
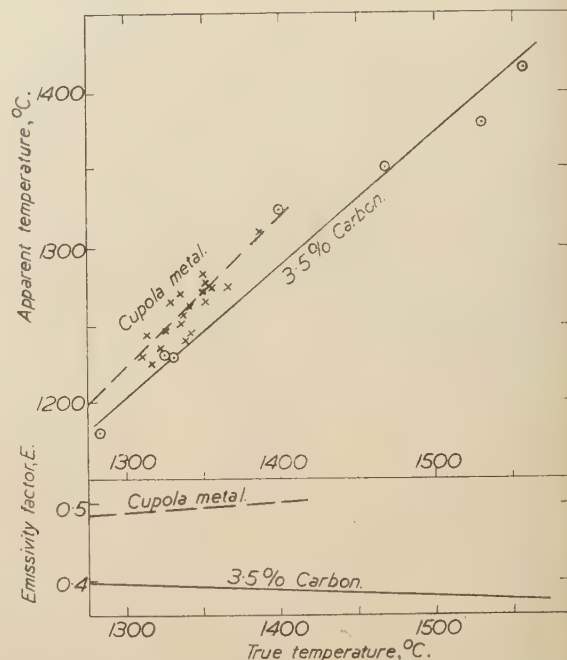


FIG. 27—Comparison of the emissivity of open-hearth and electric plain carbon steel. (a) Naeser's results⁷ and (b) Guthmann's results⁴

Reverting to the present work, Figs. 28 (a) and 28 (b) show the great variation in the emissivity of 3½% carbon metal and Armco iron, respectively, according to the method of manufacture. Under oxidizing conditions of manufacture the emissivity of the molten metal is appreciably increased.



× Cupola metal
○ 3.5% carbon steel, 20-lb. exptl. H.F. furnace, sillimanite lining
FIG. 28(a)—Comparison of cupola metal (3.5–3.7% carbon) and 3.5% carbon steel (high-frequency)

Effect of the Nature of the Lining

Figure 29, reproduced from the data given in Figs. 11, 12, and 13, shows the variation of emissivity with temperature for three types of steels melted in a 2-cwt. high-frequency furnace, using both acid and basic linings. Great care was taken during the observations and the results were accurately analysed after correcting for any temperature changes which occurred during the time interval between the corresponding observations of true and apparent temperature. Each curve was derived from approximately 12 sets of readings and the standard deviation from the mean curves was of the order of 10° C. optical.

It will be noticed that in every case the emissivity of the acid heats is lower than that of the corresponding basic heat. The statistical significance of these differences has been determined (see Appendix II), the results of which show that in the case of Figs. 11 and 13 (corresponding to Figs. 29 (a) and 29 (c), respectively) the significance is considerable, but in the case of

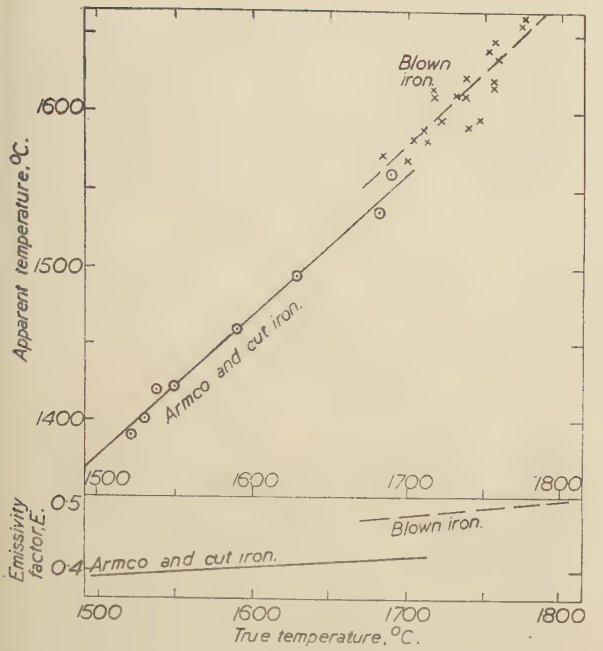


FIG. 28(b)—Comparison of blown iron with Armco and cut iron

Fig. 12 (Fig. 29b) it is relatively low. It is evident that for the same apparent brightness temperature the acid material is actually hotter than the corresponding basic heats and this feature possibly explains the general opinion expressed in the foundry that acid heats are more fluid than basic heats.

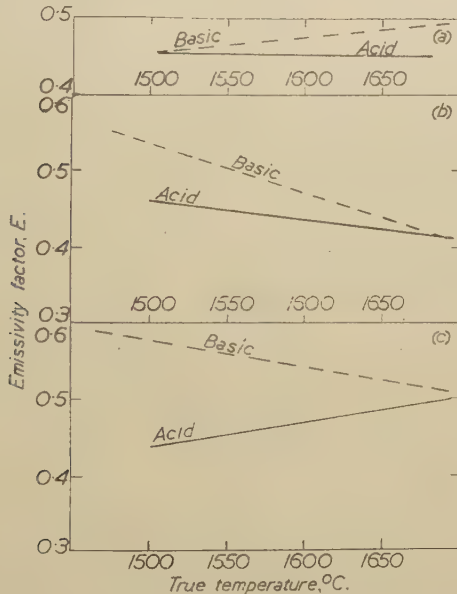


FIG. 29—Effect of the nature of the furnace lining on the emissivity of steels made in a 2-cwt. high-frequency furnace. (a) Plain carbon steel, (b) 3.5% nickel steel, and (c) 1.75% carbon steel

Effect of the Oxide Film

It is evident that this factor is the crux of the whole problem of emissivity as observed under practical conditions. The variations due to the different alloy additions and method of manufacture are influenced considerably by the oxidizability of the contained elements. For instance, chromium, which is an easily oxidizable metal, appreciably affects the emissivity of any steel to which it is added. Physical factors inherent in the practical operation may also

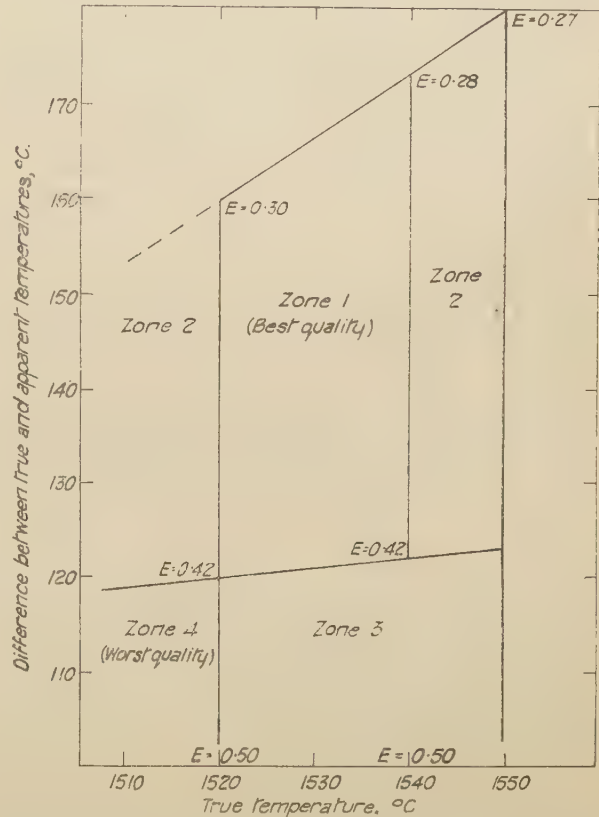


FIG. 30—Apparent and true temperature differences in assessing steel quality (Kreutzer); 0.65–0.68% carbon steels, basic open-hearth furnace

increase the probability of the incidence of an oxide film, e.g., the presence of slag, exposure of the surface of the molten metal to the action of the atmosphere, and the degree to which these agents may be affected by the melting or casting conditions, for instance, the character of the turbulence in a high-frequency furnace.

Open-hearth steel usually has a higher coefficient than electric steels of similar composition. Blown iron in the converter has a higher emissivity than Armco iron made by other processes, and cupola metal has a greater emissivity than 3.5% carbon metal made in the high-frequency furnace.

C. Kreutzer¹¹ goes so far as to claim to be able to determine the quality of open-hearth carbon steel by its emissivity. He formulated a diagram, reproduced from the papers of Naeser⁷ and Guthmann⁴ in Fig. 30, showing various quality zones according to the difference between the true and apparent temperature for various true casting temperatures. Zone 1 represents steels of the best quality and zone 4 those of the worst quality. It does not follow that the diagram is of universal application, and it may apply only to the specific conditions prevailing during the investigations concerned.

In the work of Kreutzer¹¹ referred to above, and incidentally in most of that of Guthmann⁴ and Naeser⁷ already quoted, the majority of their true temperature observations were made by the Biopix colour pyrometer, working on two wavelengths, in the green and the red wave-bands. As pointed out by W. J. Todd,⁶ this instrument does not correct for varying emissivity in general, nor for any selective emission that may be present. It does not follow therefore that their true temperatures correspond to those obtained by immersion couples.

In attempting to interpret Kreutzer's chart in the light of the present observations it is apparent that emissivity is very much a function of the surface condition of the molten stream, which in turn is influenced by process and casting conditions. Kreutzer presumably used bottom-stoppered ladles, which possibly reduced the effect of the oxide film, but even with this method of casting it is possible to obtain considerable variations in emissivity according to the position of sighting on the stream, draughting, and other shop conditions. Further considerable oxidation of the metal may occur during the operation.

Naeser⁷ quotes a difference of 70° C. in the apparent temperature between the top and bottom of a casting stream from a stoppered ladle, ascribed to surface oxidation, and he calculated that for a film 0.01 mm. thick this degree of oxidation is equivalent to 0.02% of oxygen in the steel. This worker also found that air blown on to a casting stream appreciably increased the brightness temperature of the stream and that the reverse effect could be obtained by a protective gas which would clear the oxidized surface of a 2% chromium steel held at 1650° C. W. H. Spencer⁸ and R. Hase⁹ give curves, reproduced in Fig. 31, showing the magnitude of the influence of the oxide film on the emissivity of cast iron and steel respectively. Incorporated with Spencer's data is the curve covering normal ladle surface temperatures, from which it is apparent that a slight oxide film persists in the ladle.

This subject of the effect of the oxide film on emissivity is still more complicated in that its nature and stability are of great importance. It is noticeable that the higher the temperature, the less is the increasing effect of the scum on the emissivity. Considering Figs. 8 and 26, where scum temperatures are available, it is note-

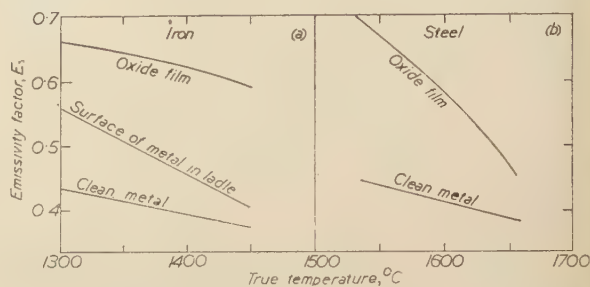


FIG. 31—Effect of oxide film on emissivity of molten iron and steel. (a) W. H. Spencer,⁸ and (b) R. Hase⁹

worthy that the emissivity of the scum decreases rapidly with increasing temperature and tends to approach that of the so-called "steel" surface at some elevated temperature. This may be a function of the viscosity of the oxide film or, as Guthmann⁴ points out, the film may decompose or pass into solution as the temperature rises. Hase⁹ found in his investigations with molten iron that up to 1450° C. (true) the oxide film persists unbroken and at this temperature has an emissivity of 0.83. Between 1450° C. and 1560° C. the scum breaks up into isolated islands accompanied by a decrease of emissivity to 0.67. Above 1560° C. no film is apparent and the emissivity decreases to a value of 0.5 at 1650° C. It is recognized that with high carbon steels the oxide films are particularly unstable at high temperatures owing to the accelerated reducing action of the carbon.

It is apparent from these investigations that the emissivity of any particular molten steel of definite composition can vary over an appreciable range according to the conditions of manufacture and casting. With plain carbon steels under normal conditions the range of variation is of the order of 0.40–0.50 above 1600° C. (true), but larger variations exist at lower temperatures (Fig. 25a). High-alloy steels show wide fluctuations of emissivity according to the alloy added, which may be ascribed in some measure to the existence of the oxide film.

By the combined use of the immersion couple and the optical pyrometer the emissivity factor for any steel can be determined under the conditions prevailing, but it does not necessarily follow that the observed factor will apply under different conditions.

Having once established the emissivity of a steel for a particular set of conditions and plant,

It is evident that any serious deviation of the coefficient under similar circumstances must point to some inherent change in the condition of the metal. This aspect of the problem would merit further investigation. From the work already done, the quantitative degree to which emissivity is affected by scumming has been determined.

CONCLUSIONS

The emissivity of molten steel under a wide range of workshop and laboratory conditions has been determined by the method of observing the true and apparent temperatures of the molten steel.

Relationships between emissivity and temperature have been derived from these observations and are in general of a straight-line character, having a negative temperature coefficient with carbon and low-alloy steels, and a positive coefficient with high-alloy steels.

Conditions which disturb the inherent relationship between emissivity and temperature have been studied, and the following factors have been found to have a pertinent influence:

(a) *Composition of the Steel*

Carbon—Below the eutectic composition varying carbon content does not affect emissivity, but above the eutectic composition the emissivity of the steel is slightly lowered by increasing carbon content.

Silicon and Aluminium—With both metals used as a deoxidant, the results as regards emissivity are erratic. Naeser's claim, that there is an optimum amount of silicon and aluminium, depending on conditions, which gives the lowest emissivity coefficient, seems reasonable.

Chromium—It is confirmed that increase of chromium content increases the emissivity of molten steel. The effect is more pronounced at higher temperatures.

Nickel—In general, nickel has little effect, but under certain conditions of melting, associated with the probable presence of slag and scum, some effect has been recorded.

Copper—A content of $1\frac{3}{4}\%$ of copper has little effect in small laboratory furnaces, but in larger furnaces the emissivity increases at high temperatures. The temperature coefficient varies with conditions (Fig. 25b).

Manganese—Manganese additions tend to increase the emissivity in industrial furnaces, but the effect almost disappears with a content below 1% in the laboratory high-frequency furnaces.

(b) *Method of Manufacture*

The size of the furnace and the process used has a pertinent influence, particularly in respect

of conditions which may give rise to slag or scum on the surface or other condition of the stream during casting.

(c) *Nature of the Furnace Lining*

The emissivity of steels melted in acid linings is generally lower than that of the corresponding steel melted in a basic lining, from which it is evident that for the same apparent brightness temperature the acid steel is actually hotter than the basic. This difference in observed emissivity may not be associated with any inherent property of the steel itself, but may be due entirely to the conditions under which the steel is cast, occasioned by the nature of the steelmaking process. Thus the lining of the containers used in founding may be acting through its influence on the physical character of the surface of the molten steel.

(d) *The Oxide Film*

The conditions which give rise to an oxide film are the crux of the problem of emissivity variations in molten steel. Increase of temperature reduces the disturbing effect of an oxide film. Any conditions which may give rise to scum or slag, for example, oxidizing or reducing conditions, can affect emissivity. The quantitative effect of this factor in relation to temperature has been determined in a number of instances.

ACKNOWLEDGMENTS

The authors' thanks are due to Mr. W. J. Dawson, Chairman of the Steel Castings Research Committee, for his interest and encouragement, and to Mr. W. J. Todd, Mr. T. H. Middleham, Dr. R. Jackson, and Mr. J. D. Cresswell for their collaboration in the course of the experimental work.

APPENDIX I—*The Basis of the Determination of Temperature and Emissivity*

The value of the emissivity has been obtained by the normal expression derived from Wien's law:

$$\log E = \frac{C_2 \log e}{\lambda} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

where E = emissivity,

C_2 = fundamental constant of the Planck equation (1:432 cm. degrees),

e = base of Napierian logarithms,

λ = wavelength of light used, cm.,

T_2 = true temperature (°C. abs.),

T_1 = apparent temperature (°C. abs.):

The calibration of the temperature scale used has been based on the International Temperature Scale. In this scale the platinum-resistance thermo-

meter is used up to 660° C. and above that temperature the electromotive force given by a standard platinum-rhodium thermocouple up to the gold point (1063° C.). Above the gold point the temperature t is determined by means of the ratio of the intensity J_2 of monochromatic visible radiation, of wavelength λ cm., emitted by a black body at the temperature t_2 , to the intensity J_1 of radiation of the same wavelength emitted by a black body at the gold point, by means of the formula:

$$\text{Log} \left(\frac{J_2}{J_1} \right) = \frac{C_2}{\lambda} \left(\frac{1}{1336} - \frac{1}{(t+273)} \right)$$

The constant C_2 is taken as 1.432 cm. degrees.

From the International Temperature Scale the actual freezing points of selected standard elements are known. These have been used for the calibration of the temperature scale in these investigations. The optical pyrometers were standardized against a thermocouple in a black-body furnace in which ionization effects are excluded. The furnace is capable of being raised to the temperature of the melting point of platinum. The points actually used were the melting point of ice, the boiling point of water, the freezing points of tin (231.8° C.), lead (327.4° C.), zinc (419.5° C.), and aluminium (660.1° C.), and the melting points of gold (1063.0° C.), palladium (1555° C.), and platinum (1774° C.). Sodium chloride (800.5° C.) was also used as a substandard.

APPENDIX II—Significance of the Relationships Found between the True and Apparent Temperature for Acid and Basic Linings (Figs. 11, 12, and 13)

Figures 11, 12, and 13 each present a comparison between the emissivities of steels made in acid linings with those made in basic linings, and the regression lines which have been drawn to satisfy the condition of least squares indicate distinct differences. The significance of these differences has been assessed by statistical tests, the results of which form the subject of this Appendix.

The statistical method employed is indicated only briefly, further details being obtainable from Fisher's book.¹²

Outline of Statistical Method Employed

The linear regression equation is of the form:

$$Y = a + b(x - \bar{x}),$$

where Y is the predicted value of y (the dependent variable) for each value of x (the independent variable); b is the regression coefficient of y on x , that is, the slope of the line; and a is the regression coefficient which determines the position of the line relative to the origin.

In determining the significance of difference between the "acid line" and the "basic line" in Figs. 11, 12, and 13, the apparent temperature has been considered as the dependent variable and the true temperature as the independent variable.

In the first place the significance of the difference in value of b , the slope, is regarded as the criterion of difference in the lines. In the case of Fig. 12, where little significance in the difference of b values was found, the coefficients a have also been considered. Comparison of a coefficients gives the significance of "shift" between lines which are parallel. The t value is a measure of the probability of the differences between the curves being due to chance causes. If this function is of a high value, the probability that the differences are due to chance is low, in other words, the greater the t value, the greater the significance of the curves.

Results

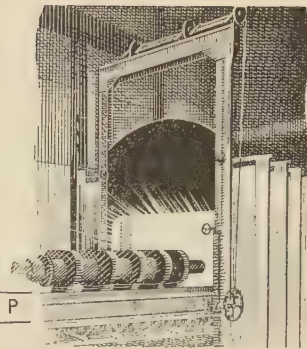
The results were as follows:

Fig. No.	Value of t	Probability of Difference in Regression Coefficients b	Significance	Conclusion
11	23.66	0.99	Very great	Slope of lines is different
13	2.70	0.985	"	"
12	1.51	0.85	Very little	Slope of lines is not definitely different
		Probability of Difference in Regression Coefficients a		
12	0.3	0.24	None	Position of lines is very similar

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IRON AND STEELWORKS ENGINEERING



THE IRON AND STEEL ENGINEERS GROUP

THE IRON AND STEEL ENGINEERS GROUP REPORT OF THE SECOND MEETING

THE SECOND MEETING OF THE IRON AND STEEL ENGINEERS GROUP of the Iron and Steel Institute was held at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 11th December, 1946. Mr. W. F. CARTWRIGHT (Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd.), Chairman of the Group, presided, and Dr. C. H. DESCH, F.R.S., President of the Iron and Steel Institute, was also present.

AT THE AFTERNOON SESSION papers on "Roll-Neck Bearings" were read by Mr. J. M. BORLAND, Mr. L. R. PEARSON, Mr. F. W. JONES and Mr. G. R. WALSHAW. The discussion was opened by Mr. J. S. MAYNE who spoke of fluid-film bearings.

THE PROCEEDINGS OF THE MORNING SESSION were published in the March issue of the *Journal* (pages 423-441).

PROCEEDINGS OF THE AFTERNOON
SESSION : 2.15 P.M. to 4.30 P.M.*

ROLL-NECK BEARINGS

The **Chairman** : It was originally intended that Mr. C. A. Phipps should speak this afternoon, but he caught a germ in Sweden and was laid up. Also, at that time Mr. Knight was in the United States and out of reach, and I took a gloomy view of the prospects and was prepared to adjourn the meeting ; but then Mr. Knight turned up, and Dr. Ford and Mr. Post arranged for the four short papers which we are to hear on different types of bearings. My only fear now is that we may not be able to keep the authors within bounds, because they have a great deal to say.

The discussion was then introduced by the following four short papers :

"White-Metal Bearings Applied to Hot-Steel Rolling Mills," by Mr. J. M. Borland, (Messrs. Colvilles, Ltd.).

"Roller Bearings," by Mr. L. R. Pearson (Messrs. Richard Thomas and Baldwins, Ltd.).

"Synthetic-Resin Bearings," by Mr. F. W. Jones (Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd.).

"Oil-Film-Type Bearings," by Mr. G. R. Walshaw (Appleyby-Frodingham Steel Co., Ltd.).

* The Proceedings of the Morning Session—a paper on "Lubrication in Iron and Steel Works Engineering," by Mr. H. J. Knight, with discussion—were published on pages 423-441 of the *Journal*, March, 1947.

WHITE-METAL BEARINGS APPLIED TO HOT-STEEL ROLLING MILLS

By J. M. Borland, A.M.I.Mech.E.*

ROLL-NECK BEARINGS

THE subject of roll-neck bearings has always been highly controversial, and in any discussion, even between men of experience, there will be many different opinions expressed as to the type of bearing most suited to a particular application.

The views expressed in this paper are not merely opinions, but are based on facts obtained from lengthy experience of bearings which have operated under all manner of conditions, usually extremely arduous. The designs discussed have been arrived at by a process of progressive evolution, original design having been modified as suggested by continuous experience under actual working conditions.

Briefly, the requirements of a roll-neck-bearing assembly are as follows :

- (a) Reliability and efficiency.
- (b) A design which permits ease and speed of roll changing.
- (c) Low bearing cost per ton of steel rolled.

For heavy plant, such as blooming, slabbing, plate, and section mills, the simpler white-metal

* Messrs. Colvilles, Ltd.

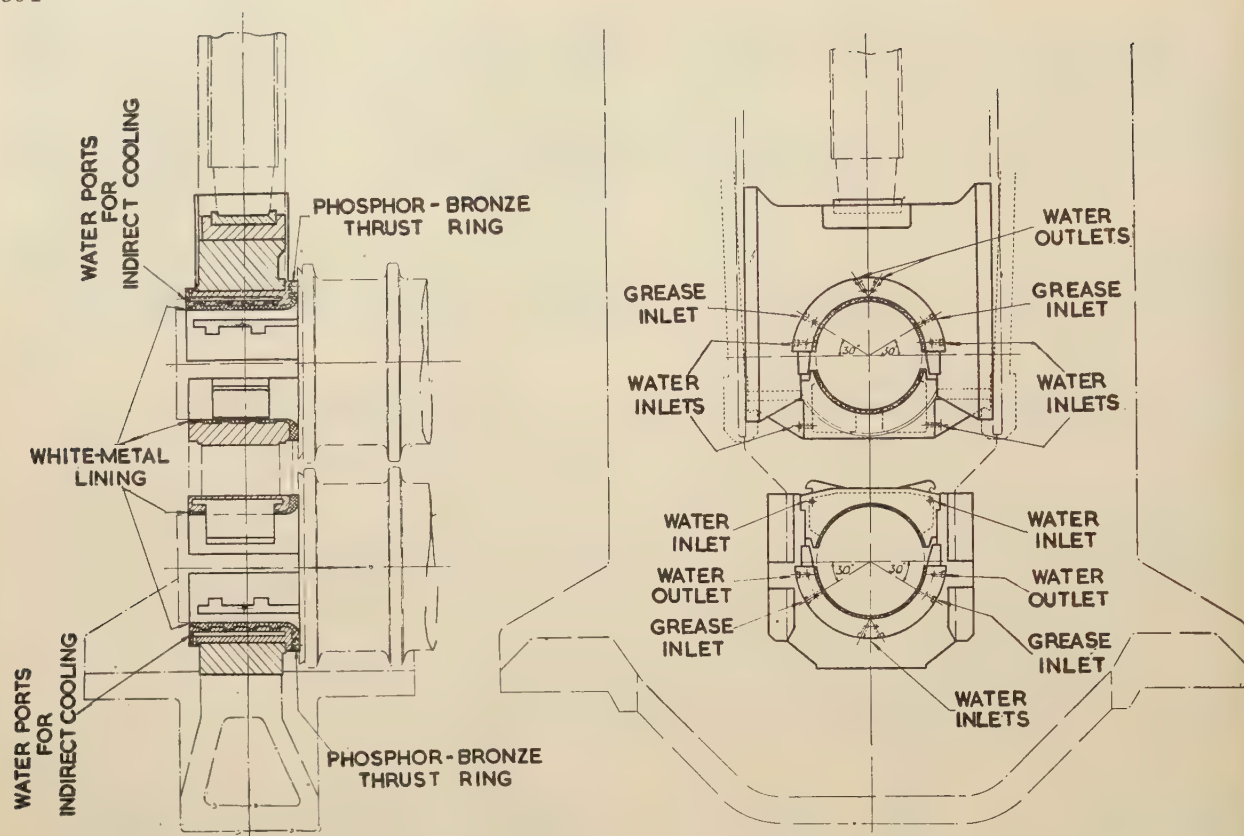


FIG. 1—Arrangement of white-metal bearings for blooming and slabbing mills

bearing, grease lubricated, is generally preferred to the fluid-film-lubricated bearing, which is a precision job and imposes limitations on the satisfactory design of a universal coupling. The white-metal bearing is also generally preferred to the roller bearing, to which there is a fundamental objection in that the normal size of roll neck, considered in relation to the working centres of the rolls, will seldom allow adequate space for the accommodation of suitably proportioned bearings.

The requirements of the bearing metal are :

- (i) Ability to withstand heavy pressure without undue deformation.
- (ii) Ability to bed itself to the roll neck without causing excessive local heating.
- (iii) Ability to prevent seizure in case of failure of lubrication.
- (iv) Ability to resist corrosion by lubricant and water.
- (v) Low coefficient of friction.

White metal meets the above requirements, the type of white metal to be used being determined by the conditions prevailing in the installation under consideration. The proper choice of white metal does not of itself produce a good bearing, as the performance of the bearing is also dependent

on its design, manner of casting, maintenance, and operating conditions. Faulty design, casting, and lubrication are probably the most frequent causes of bearing failure.

Blooming and Slabbing Mills

A typical arrangement of white-metal roll-neck bearings as successfully applied to blooming and slabbing mills of the two-high reversing type is shown on Fig. 1. It will be seen that the bearing shells, which are lined with a 66% lead-base white metal, are seated in chocks and are identical for top and bottom rolls. The bearing embraces about 180° of the roll neck and is provided with two axial grease-grooves running almost the whole length of the bearing and situated at 30° from the horizontal centre-line. End thrust is taken on a phosphor-bronze ring attached to the shell and lubricated from an extension of the grease-grooves. The grease supply is effected by means of a mechanical pumping unit.

To ensure that favourable temperature conditions obtain, direct and indirect cooling are applied. Indirect cooling is obtained by the passage of water through axial ports in the body of the bearing shell, so connected one with the other that the water passes back and forth along the length

d around the arc of the bearing. Two water jets and two outlets are provided. Direct cooling is obtained by so designing the top-roll carriers and the bottom roll-neck covers that relatively large slow-moving bodies of water are in contact with the necks, this method reducing the possibility of the grease being washed from the necks. To guard against the possibility of interfering grease and water services at their entry to the bearings, different sizes of connections are provided for each.

Bearing Performances

The lives of the top- and bottom-roll bearings on 42-in. blooming mill, a 44-in. blooming and slabbing mill, and a 35-in. slabbing mill, are given in Table I.

TABLE I—*Bearing Performances*

Bearings	Life of Bearings, tons		
	42-in. Blooming Mill	44-in. Blooming and Slabbing Mill	35-in. Slabbing Mill
Top roll, drive side ...	1,361,000*	516,000	448,000*
„ „ outside ...	1,209,000	650,000*	448,000*
Bottom roll, drive side	985,000	188,000	227,000
Bottom roll, outside...	85,000	250,000*	227,000

* Bearing still in service.

On the 42-in. blooming mill the tonnage for the bottom outside bearing compares unfavourably with that for the other bearings, the reason being that this is the bearing next to the ingot pass, and, owing to the shedding of scale, the thrust ring becomes worn before the white metal has reached the end of its useful life. Replacement of the thrust ring would allow of the bearing remaining in service for longer periods, but it is usually considered preferable to change the complete bearing rather than risk a stoppage between roll changes. In the case of the 44-in. blooming and slabbing mill, the change-over from bronze bearings and block grease lubrication to white-metal bearings and automatic lubrication resulted in a power saving of 20%. It is also worthy of note that the cost of grease and relining of bearings works out at 0.45*d.* per ton of steel rolled, of which cost grease is responsible for 0.3*d.* When running on bronze bearings the cost of bearings alone amounted to 0.6*d.* per ton of steel rolled, at the level of present-day costs.

Plate and Section Mills

The successful application of plain white-metal bearings to plate and section mills of the two-high type presents many problems, one of which is the lack of consistency in performance. The conditions under which the bearings have to operate differ from those obtaining in blooming and

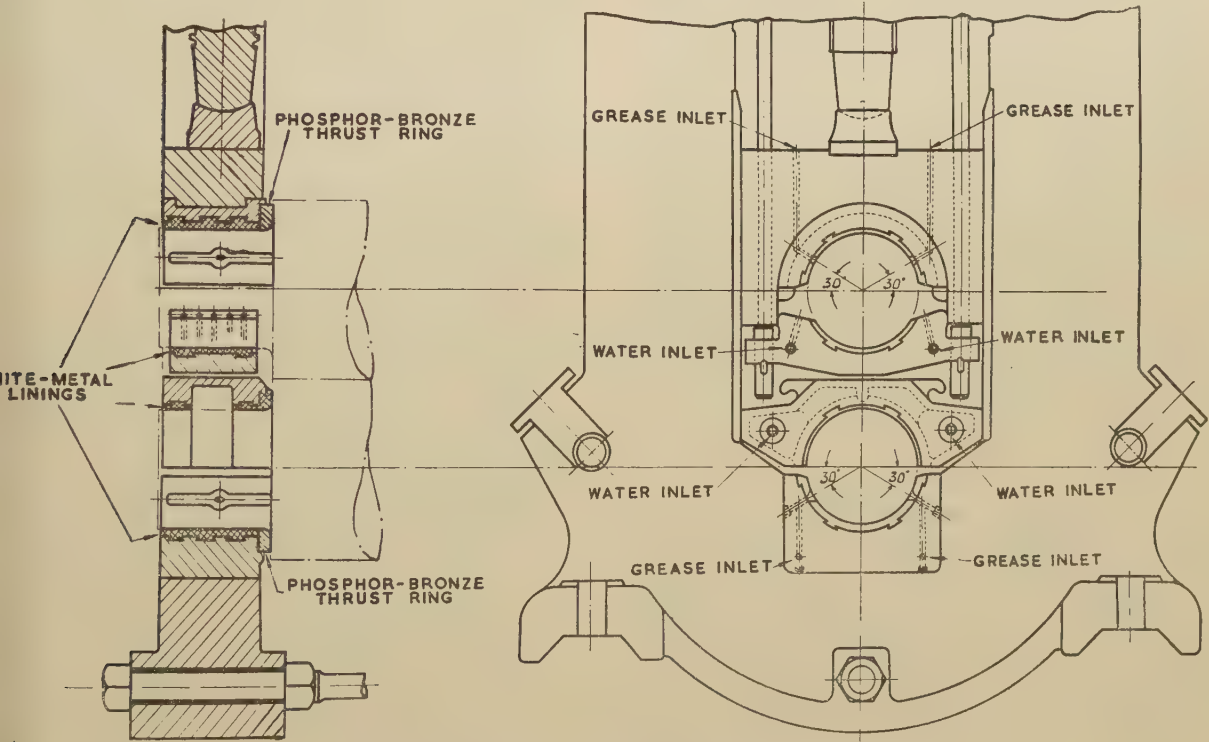


FIG. 2—Arrangement of white-metal bearings for 18-in. bar mill

slabbing mills, in that the speed of the rolls and the rolling loads are greater in the case of plate mills, and the speed of the rolls is greater in the case of section mills. In addition, the greater frequency of roll changing, particularly in the case of section mills, provides more opportunities for injury and contamination of the bearings and roll necks, and also the possibility of varying sizes of necks being applied to the bearings. All of these are conditions unfavourable to long bearing life. The bearing life on the 32-in. finishing stand of a bar mill has reached 50,000 tons, and it is hoped that modifications now proceeding will result in greater tonnages being realized.

The bearings of a 9-ft. three-high plate mill equipped with 36-in. dia. top and bottom rolls and a 24-in. dia. middle roll, have given very encouraging results. The top- and bottom-roll bearings, which are lined with a 63% tin-base white metal, have an average life of 60,000 tons and, on occasion, 80,000 tons have been obtained on the bottom-roll bearings. It is confidently expected that minor modifications now in progress will result in still longer life.

Fig. 2 shows the arrangement of bearings for an 18-in. two-high two-stand bar mill. It will be seen that the bearings, which are lined with a 66% lead-base white metal, embrace about 180° of the roll necks and are provided with axial grease-grooves running almost the whole length of the bearing. The grease-grooves are situated at 30° from the horizontal centre-line, their grease supply being obtained from a mechanical grease pump. Only direct cooling water is applied to the roll necks. The conversion from bronze bearings and block grease lubrication to white-metal bearings and automatic lubrication has resulted in the life of the bearings being greatly increased, and the power consumption reduced by about 40%. The white-metal bearings originally installed have been in service in the case of the roughing stand for about two years and in the finishing stand about 18 months, and are still carrying on, whereas the bronze bearings had a life of about six weeks.

Lubricant

The type of grease required is one which will be capable of maintaining a film on the roll neck under conditions of load, temperature, and the application of cooling water. The softest grease consistent with meeting the requirements should be used. On the before-mentioned mills a grease having a liquifying temperature of 190° F. and consisting of 90% of paraffin-base oil, the remaining 10% consisting of lime soda and an additive

to give the property of adhering to the necks, has proved satisfactory.

Lubrication Systems

In order that optimum conditions shall be obtained without wastage of grease, it is necessary to provide a mechanical pumping unit which will ensure reliability and regularity of supply and at the same time provide means of regulating the quantity of grease fed to each bearing. The pipelines connecting the pumping unit to the bearings should be as short and direct as possible, with pipe bores of reasonable size so that the wear and tear on the lubricator is a minimum. As few joints as possible should be used in the pipelines, and those that are provided should be placed in accessible and, if possible, visible positions. The pumping unit should be housed in a well-finished and well-lit compartment, not just in a hole in the floor as is sometimes the case, and under certain conditions it may be desirable to house it with other lubrication units attached to the mill, so that they are all under the scrutiny of the lubrication attendant.

The following three types of automatic pressure-feed grease-pumping systems are in general use:

(1) The multi-point motor-driven pump, which consists of a number of plunger-pump units, each adjustable for a rate of supply to suit individual bearing requirements and arranged around the periphery of a revolving eccentric, which provides the reciprocating motion of the plungers. The grease is contained in a canister and is fed to the pumping units by means of a revolving scoop. Each pumping unit is connected by pipeline to one lubricating point.

(2) The multi-point battery set, which consists of a number of cylinders mounted on a frame, each cylinder being equipped with a piston, on one side of which is the grease to be fed to the bearing and on the other side pressure oil for feeding the grease to the bearing. Pressure oil to each cylinder is provided by a multi-unit oil pump, one unit being connected to each cylinder, and each unit has its own adjustment so that the rate of supply of grease from each cylinder can be adjusted to suit individual bearing requirements. The cylinders are charged by means of an air-driven pump set into the grease barrel, this method reducing the risk of contamination of the grease. Each cylinder is connected by pipeline to one lubricating point, and a pressure-gauge is fitted on each cylinder unit so that a ready means of indicating conditions in each line is available.

(3) The twin-line pumping system, which

consists of a central piston-type pump and reservoir from which two main supply lines are led around the mill. The two main lines pass through measuring valves, conveniently positioned to suit the points to be lubricated, and form a complete circuit, terminating at a reversing and control valve in the central unit. The principle of operation of the system is that the pump forces the grease into one of the two main supply lines while relieving the other of pressure, the pressure differential being used to operate the valves set across the two main lines and so discharge a measured quantity of grease from the valves to each bearing. The quantity of grease discharged by each valve can be adjusted, and means of indicating that the valves are operating is provided. The frequency of operation of the system is controlled by an electric clock, which provides an adjustable means of starting, and the reversing valve on the end of the loop operates automatically to stop the system.

Type (1) has not been altogether satisfactory, owing to the difficulty of obtaining reliable pumping units. It is unfortunate that the best type of pump so far used has been of pre-war Continental construction.

Type (2) has given good results, the primary virtue in the design being that the pressure-pumping elements deliver oil in a closed circuit which cannot be contaminated by scale, water, or other impurities. The set could be more robustly designed with advantage to steelworks users, and at the same time larger oil and grease passages would be a decided improvement.

Type (3) has given good results on the lighter types of grease, but trouble has been experienced with heavier grease, owing to cavitation around the pump unit creating air locks in the system.

CONCLUSIONS

It may be said that plain white-metal bearings have fully justified their application to hot-steel rolling mills, and in those cases where their performance has not reached the desired level lack of success may be due to incomplete knowledge of the conditions to be met by the bearings. Further progress will be made by extended study of the following aspects as applying to any particular bearing:

- (a) The actual loads to be carried.
- (b) The quality of white metal.
- (c) The allowable bearing pressures.
- (d) The thickness of the lining.
- (e) The casting procedure.
- (f) The class of lubricant.

ROLLER BEARINGS

*By L. R. Pearson, A.M.I.Mech.E.**

YOU will have gathered from your Institute's circular that, in company with other speakers, I have been called upon at rather short notice to provide something informative and of interest on the subject of roll-neck bearings; my paper is confined to roller bearings in the light of our experience at Ebbw Vale.

After a short discussion with your Chairman (Mr. Cartwright) it became quite clear that I should have to limit myself to the most important application of roller bearings that we have, namely, the large back-up bearings and the attendant work-roll bearings—all from our four-high mills—and all the remarks that follow are confined to those two applications as set out in Figs. 1 and 2, which show typical assemblies of spherical roller bearings and taper roller bearings, respectively.

REASON FOR SELECTION AND PREFERENCE TO OTHER TYPES

The first section of the questionnaire sent to me asked the reason for selection and preference to other types. Now, that is the easiest of all the questions to answer, and a short reply would be that we were completely in the hands of our American friends and advisers; it was an existing American mill that was chosen as the prototype of the proposed Ebbw Vale mill—and that mill was equipped with roller bearings.

It is possible to elaborate a little on that and point out that any prototype of the Ebbw Vale mill must have been on the drawing board before 1932—the date at which the oil-film bearings first appeared on American strip mills.

Since that date we know that the oil-film bearing has become a very serious competitor of the roller bearing and that it has certain very desirable features, but I see that the roller-bearing makers have taken up the challenge and have put on the market a new "close-clearance" type of bearing which permits larger neck diameters and a better distribution of the stresses.

STATISTICS OF TONNAGES, FAILURES, AND REASONS FOR FAILURES

The second section of the questionnaire asked for statistics of tonnages rolled, failures, and reasons for failures. I sent forward to your Secretary some extracts from our works' routine "bearing-history reports," which he kindly

* Messrs. Richard Thomas and Baldwins, Ltd., Ebbw Vale.

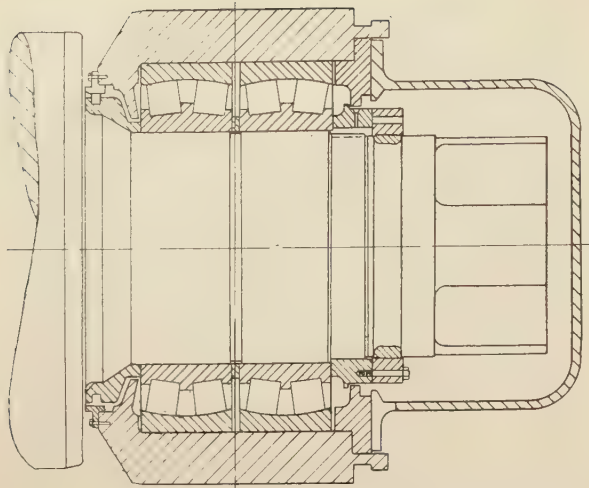


FIG. 1—Typical spherical-roller-bearing assembly

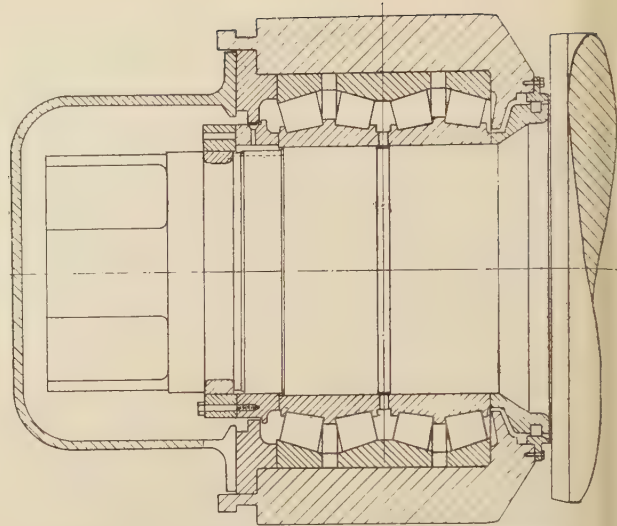


FIG. 2—Typical taper-roller-bearing assembly

offered to have stencilled and then circulated to the interested members.

These extracts have been reproduced in Table I, and they do show the statistics called for and also indicate the policy which we have developed at Ebbw Vale of taking full advantage of the close clearances of the new bearings in the positions where they are most needed, that is, the five-stand cold-reduction mill, then pass them on to the other mills at a rate to cover normal wastage—which has been very much a case of trial and error.

Fig. 3 has been included to indicate to those

who are not familiar with the types of damage that occur in these larger roller bearings just what we mean by “spalling” of rollers and tracks. The damage is possibly due to normal fatigue and to severe shock loads when abnormal conditions exist in the mill, such as a “cobble,” where two or more thicknesses enter the bite of the rolls, or the entry with the strip of a spalled piece off the top back-up roll. The result is an area on roller or track that has become overstressed or work-hardened, and this area gradually separates from the parent metal and then suddenly falls

TABLE I—*Extracts from Bearing-History Reports, Messrs. Richard Thomas and Baldwins, Ltd., Ebbw Vale*

Type of Bearings	Service in Five-Stand Tandem				Service in Hot Mill		Service in Three-Stand Tandem		Total Service to Date		Present Conditions
	Nos. 4 and 5 Mills		Nos. 3, 2, and 1 Mills								
	Hr.	Tonnage	Hr.	Tonnage	Hr.	Tonnage	Hr.	Tonnage	Hr.	Tonnage	
Hot- and cold-mill	4,486	112,920	9,680	254,080	Nil	Nil	4,621	183,000	18,787	550,000	No damage throughout.
Back-up	4,402	110,520	9,713	256,480	Nil	Nil	3,857	133,000	17,972	500,000	Spalled tracks while in five-stand rough condition.
	4,965	130,140	9,222	239,860	Nil	Nil	1,911	70,000	16,098	440,000	
”	3,476	89,865	4,419	119,820	Nil	...	Nil	...	7,895	209,687	Spalled rollers waiting replacement.
”	1,501	40,612	1,135	29,788	Nil	...	Nil	...	2,636	70,400	For repair—spalled cups and tracks.
”	3,103	80,120	10,170	267,080	2,259	213,303	Nil	...	15,532	560,503	Spalled rollers and cone track.
”	5,594	144,650	8,169	209,223	2,866	207,436	Nil	...	16,629	561,311	Spalled rollers while in five-stand.
”	5,894	153,892	8,269	213,938	256	25,984	Nil	...	14,419	393,814	Spalled rollers at 6,000, 7,500, and 9,600 hr. in five-stand.
”	2,433	61,142	4,613	118,787	12,733	1,133,903	482	17,762	20,261	1,332,594	No damage throughout.
”	3,873	94,306	5,788	153,675	8,491	795,330	Nil	...	18,152	1,043,312	Spalled rollers and tracks 5,800, 7,400, 8,700, and 9,600 hr. in five-stand.
”	3,215	75,392	1,919	44,771	8,395	685,368	Nil	...	13,529	805,531	Scrapped with spalling of one third of circumference; cone-track cup, cones, and rollers indented.
”	2,363	65,044	3,819	107,512	1,556	132,289	3,595	123,495	11,323	428,340	Scrapped with bad spalls which developed while in three stand after being repaired during hot-mill life.

Note—It should be understood that the practice at Ebbw Vale is to instal all new back-up bearings for their first run in the five-stand cold-reduction mill, then either to the hot mill or the three-stand cold-reduction mill.

away, doing damage of varying degree to rollers and tracks.

The effect on bearing life and tonnage of our policy at Ebbw Vale of transferring the back-up bearings from mill to mill throughout their life, and how the apparent tonnage figures are affected by retaining these bearings for longer periods in the five-stand cold-reduction mill, are shown in Fig. 4.

INSTALLATION AND MAINTENANCE COSTS

In dealing with the third section of the questionnaire, which invited information on installation and maintenance costs, grease, oil, and water, I found some difficulty in defining the term "installation" in the case of our four-high mills, as so much could be included under that heading as to take this paper far beyond the time limit allowed for it, so I have omitted all such items as chocks, hydraulic equipment, window plates, pressure pads, etc., and with these items eliminated you have to multiply the original cost per

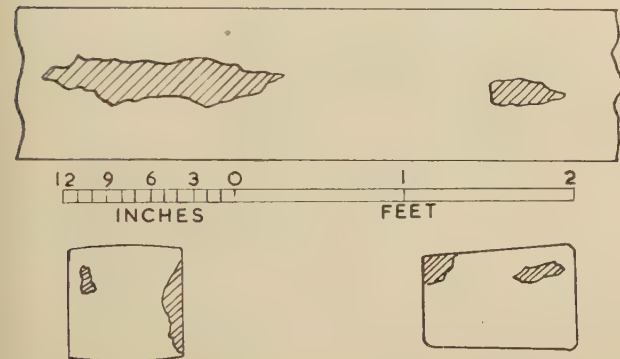


FIG. 3—Typical failures of tracks and rollers owing to spalling

bearing by the number in the mill, plus the spares necessary to keep that number serviced. I figure that in addition to the four back-up bearings in the mill we need another four in reserve, either ready to go in or in process of cleaning and assembly. If, therefore, you multiply the price of the bearing by 8 you then have the installation cost of one set of back-up bearings for one stand, plus any stores stock determined by the delivery position of this type of equipment.

To give an actual bearing cost which would be applicable to an individual hot-strip mill or to three- or five-stand cold-reduction mills operating as separate units is very difficult, as our method of usage of back-up bearings at Ebbw Vale compli-

cates the costing very considerably, but it can be given in two ways :

- (1) An overall cost of 10*d.* per ton, based on a cold-reduced make of 450,000 tons. This actually covers (a) 550,000 tons per annum rolled in the hot mill to the coiled stage, (b) 450,000 tons of cold-reduced material in the three-stand and five-stand mills, rolled down to sheets at 26 gauge and tinplate at 33 gauge, and (c) 110,000 tons of cold-reduced sheets from

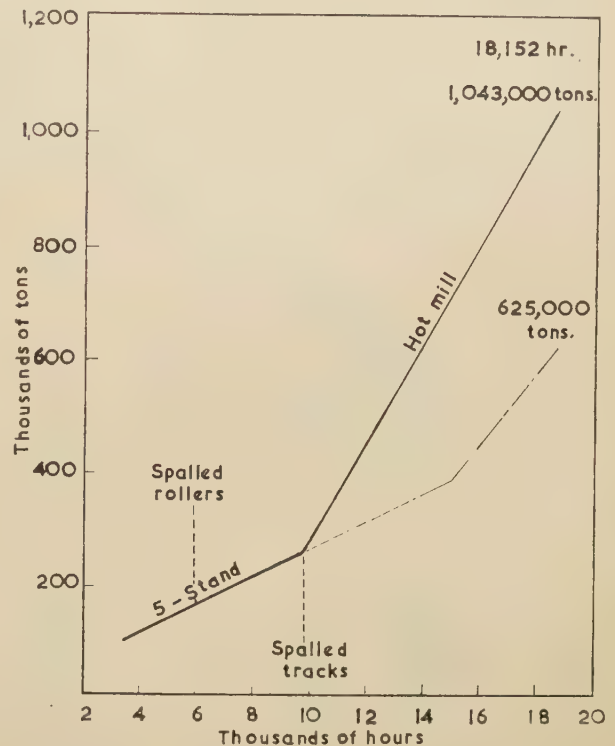


FIG. 4—Hot- and cold-mill back-up bearing : Comparison between hot- and cold-mill duty

the three-stand mill, rolled through our two sheet skin-pass mills, with a combined installation of 68 bearings in 17 stands operating at any one time.

- (2) A cost can also be expressed at so much per bearing, and if a figure of 3,000,000 tons in the hot-strip mill is taken as a divisor this would give a cost of approximately 0.096*d.* per ton per bearing.

In addition, we have three tinplate temper mills, an 80-in. cross-rolling mill, and two two-high sheet skin-pass mills, but these use odd bearings and do not affect our cost figures appreciably.

To this has to be added the bearing share of our roll-shop costs, which, again for the foregoing

reasons, is very difficult to express as a direct cost, but a figure of 11*d.* per ton can be taken to cover all the special servicing that has to be so carefully maintained throughout the life of each bearing, and the dismantling of all bearing chocks from the

thoroughly cleaned, removed, and drained off, then placed on a special table for parting and examination; any scuffed or spalled areas are carefully fettled with a pencil grinder.

Any roller too badly damaged is removed and

TABLE II—*Servicing Schedule for Mill Bearings*

Locations	Types in Use	Service Interval		
		Hot Mill	Five-Stand	Three-Stand
Hot and cold mills	Back-ups	{ Top ... 6 weeks	4 weeks	8 weeks
		{ Bottom ... 3 "	2 "	8 "
Hot mill	Work-roll	6 weeks.		
Cold mill	Work-roll	26 weeks		

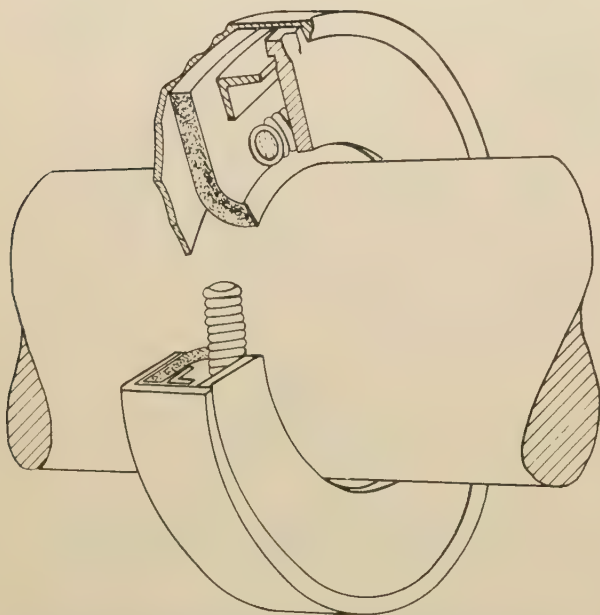


FIG. 5—Typical "garter-spring" type of seal

used rolls and their re-assembly on the newly ground ones, the handling of all rolls from the roll shops to the mills, and many other duties included in the general term "roll-shop" costs. The servicing schedule at Ebbw Vale is set out in Table II.

The bearings so listed are serviced in the following manner: The bearing is removed from the chock and placed in a bath of boiling Solvac for 1 hr., removed, and allowed to cool. It is then placed in a paraffin swilling tank and

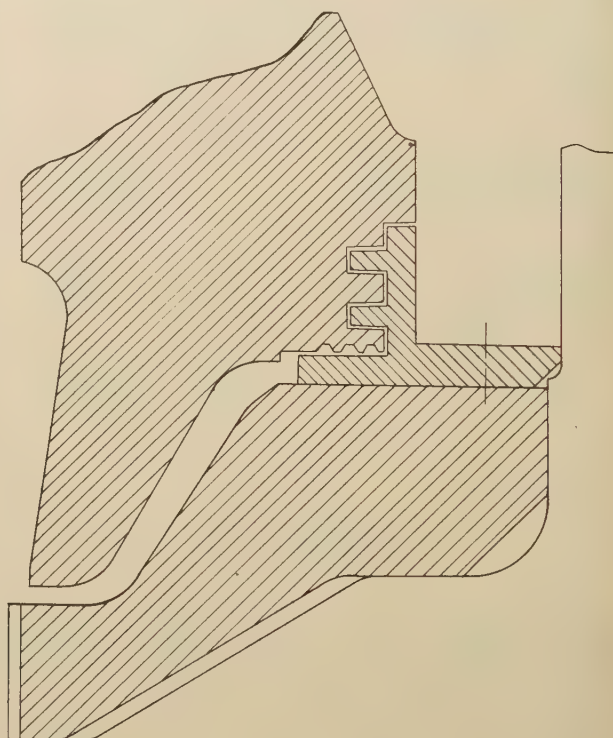


FIG. 6—Experimental "labyrinth" seal

replaced by a carefully matched one by the makers. Any cup or cone too badly spalled to provide one load zone is replaced by the makers.

After the above servicing the bearings are re-assembled in their chocks ready for the next run in the mill, according to the timetable for changing in that particular mill. Great care has

to be taken when re-assembling to keep all like-marked surfaces together and the outer cups rotated to a new load zone.

Grease Specification and Costs

The cost of grease per ton of steel rolled is 1.39d. for the hot-strip mill and 2.71d. for the five-stand mill. These figures include certain

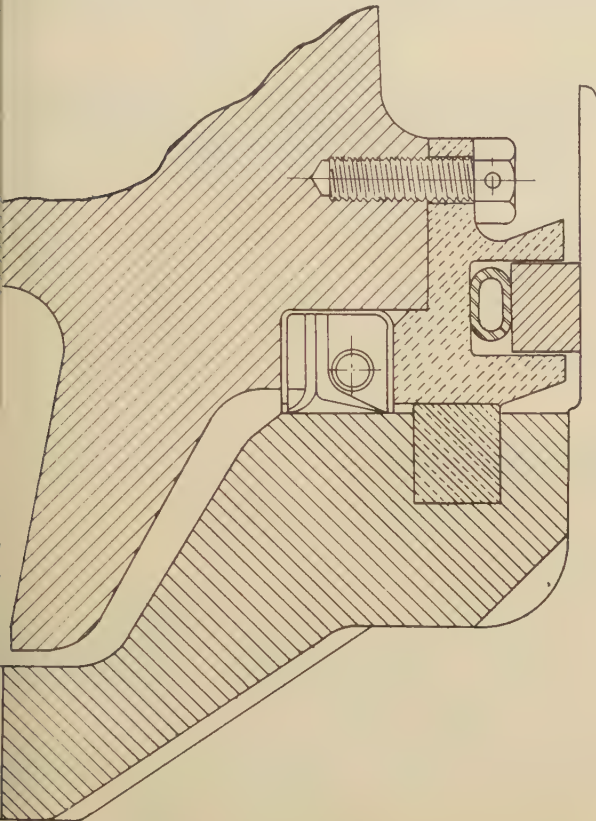


Fig. 7—Experimental sealing on horizontal and vertical surfaces

ancillary equipment, such as approach and run-out tables, etc. Oil and water do not apply in the Ebbw Vale installation.

The grease specification is as follows :

Lime soap	...	...	15%.
Lead soap	...	...	5%.
Open flash point	...	...	410° F.
Consistency	...	...	270 mm.
Moisture	...	...	1%.
Sulphur	...	...	2%.
Load test by B.T.	...	...	43 lb.

Before leaving the subject of grease, I must bring forward the vexed question of seals, and Figs. 5, 6, and 7 will indicate some of the lines we are now exploring at Ebbw Vale.

TABLE III—Five-Stand-Mill Rolling Schedule

Hot-mill band, in.	Item 1 0.083 × 37	Item 2 0.083 × 32	Item 3 0.083 × 29	Item 4 0.083 × 23
Finished gauge, in. ...	0.011	0.011	0.011	0.011
Delivery gauge, in. :				
Stand F1 ...	0.062	0.060	0.059	0.057
Stand F2 ...	0.040	0.040	0.040	0.039
Stand F3 ...	0.026	0.026	0.027	0.026
Stand F4 ...	0.017	0.017	0.018	0.017
Stand F5 ...	0.011	0.011	0.011	0.011
Reduction, in. :				
Stand F1 ...	0.021 (25.3%)	0.023 (27.7%)	0.025 (29.5%)	0.026 (31.3%)
Stand F2 ...	0.022 (36%)	0.020 (33.3%)	0.019 (32.9%)	0.018 (31.8%)
Stand F3 ...	0.014 (35.6%)	0.014 (34.8%)	0.013 (33.3%)	0.013 (33.8%)
Stand F4 ...	0.009 (36.3%)	0.009 (33.9%)	0.009 (33.7%)	0.009 (33.3%)
Stand F5 ...	0.006 (33.6%)	0.006 (34.2%)	0.007 (36.6%)	0.006 (36.0%)
Speed, ft./min. :				
Stand F1 ...	195	238	282	290
Stand F2 ...	305	355	420	425
Stand F3 ...	475	545	630	640
Stand F4 ...	730	825	950	960
Stand F5 ...	1100	1300	1500	1500
Current, amp. at 500 V.:				
Stand F1 ...	900	900	700	600
Stand F2 ...	1400	1400	1350	1300
Stand F3 ...	1500	1500	1500	1400
Stand F4 ...	1500	1500	1500	1400
Stand F5 ...	2500	2500	2500	2400
TOTAL ...	7800	7800	7550	7100

Mill Force when Rolling Item 2

Stand F1	...	2,000,000 lb.
Stand F2	...	1,200,000 lb.
Stand F3	...	1,200,000 lb.
Stand F4	...	1,400,000 lb.
Stand F5	...	1,500,000 lb.

* Running loads shown. Acceleration peaks, say, 50% above this.

POWER CONSUMPTION

I now come to the last two sections of the questionnaire, and I propose to amalgamate these, as they are so closely linked.

It is difficult to set out figures for power consumption in the case of our hot- and cold-strip mills, as to be of value they should be related to some other known type of bearings performing a similar duty. We have no such basis for comparison, but it can be stated that our overall power consumption in the hot-strip mill is 80 kWh. per ton of coiled strip, and in the cold-reduction mills 95 kWh. per ton of coiled strip. Power consumption is, of course, influenced by the screw pressure used, and the term "mill force" represents this. In other words, it is the separating force between the rolls acting upon the mill standards

via the bottom seating and the mill screw at the top, and at Ebbw Vale we have registered such pressures of well over 2,000,000 lb.

It is realized, of course, that this "separating force" is not the specific rolling pressure but only one factor in the calculations, the others being contact area, width of strip, gauge reduction, and the square of the work-roll radius.

The rolling schedule for the five-stand mill, and the mill-pressure readings when rolling 0.083×32 -in. band, are given in Table III.

ACKNOWLEDGMENT

In conclusion, I wish to acknowledge with thanks the permission given me by the Directors of Messrs. Richard Thomas and Baldwins, Ltd., to present the results of our experience at Ebbw Vale.

SYNTHETIC-RESIN BEARINGS

By *F. W. Jones, B.Sc., M.I.Mech. E.,
A.M.Inst.C.E.**

I—REASONS FOR SELECTION OF SYNTHETIC-RESIN BEARINGS

WHEN the Cardiff works of Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd., were re-built during the years 1934 to 1936 it was intended to use bronze and white-metal bearings on the blooming and light-section mills and Morgoil oil-film bearings on the continuous billet mill. The technical literature at that time, however, made it quite clear that moulded synthetic bearings made of resinous compounds and fabric were already operating on light-section mills with success, the power consumption being less than that on mills equipped with bronze or white-metal bearings. Ball or roller bearings were not considered to be a feasible proposition on account of the great number of rolls involved, each one of which would have to be fitted permanently with its own set of bearings. Attention was therefore directed to synthetic-resin bearings, on account of the savings that were claimed could be made by their use.

The claims made for these bearings included the following:

(a) Reduction in friction, with consequent saving in power.

(b) The wear on the bearings being less, the rolls maintained their gauge setting for a much longer period of time, giving a higher standard of finished product.

(c) Owing to the copious supply of cooling water on the bearings and the insulating properties of the bearings themselves, the roll necks are far less prone to fire cracks.

(d) Reduction in general maintenance costs, including consumable stores. (The reduction in grease alone was to the extent of $\frac{1}{2}$ ton to as much as 1 ton per week on the blooming mill.)

(e) Cleanliness.

After exhaustive enquiries it was decided to equip the new 21-in. light-section mill with synthetic-resin bearings from the time of its installation; the success obtained on this mill was such that the Management were encouraged to consider the adoption of this type of bearing on the 40-in. blooming mill.

The project was started in November 1936. Communications and discussions took place with

* Messrs. Guest Keen Baldwins Iron and Steel Co. Ltd.

the bearing manufacturers, and drawings for the alterations necessary to the chocks, for the laying of water mains, and for the installation of filters to ensure an ample supply of cooling water, were made. The actual conversion itself took until September 1937, when the mill started rolling on moulded synthetic-resin bearings. To the best of the author's knowledge, this was the first large reversing mill in the world to be fitted out with such bearings, and the success of the venture was doubted by many.

II—CONSTRUCTION AND ARRANGEMENT OF CHOCKS WITH BRONZE AND WITH SYNTHETIC-RESIN BEARINGS.

(a) *Bronze Bearings*

With bronze bearings the top-roll chock is fitted with a "carrier bearing," which is supported by bolts and springs from a crosshead on the main screw and moves in direct relation to the main portion of the chock. There is no other mechanical connection between the chock and the carrier. The bottom-roll chock is fitted with a keep to exclude foreign matter as much as possible. The brasses for both chocks were made with a flange to cater for the roll thrust.

The arrangement was very similar to an ordinary plummer block and brass, except that the back side of the brass in this case had a zigzag water channel cast in it. This channel passed from one end of the brass to the other, axial with the roll neck, then back again, repeating the process until the whole of the pressure area was utilized. Water was introduced into the face of the chock at one side; it then passed through the zigzag channel, finally passing out at the exit on the other side of the face.

Reliance was placed on the metal-to-metal joint between the machined face of the chock and the machined face of the brass to ensure that the water traversed the whole length of the channel.

It was found in practice that the zigzag channel left a raised impression on the chock face under working pressures. This raised impression was a very great nuisance when fitting new brasses.

The grease for lubrication was introduced through drilled passageways in the brasses by means of a mechanical pump.

(b) *Synthetic-Resin Bearings*

In order to utilize the sets of chocks originally supplied for bronze bearings, a slight modification was necessary. To compensate for the thinner moulded synthetic-resin bearing (1 in. instead of 2-3 in.) a steel liner was machined and fitted into the chock bore. This holds the moulded

lining, which is prevented from turning by two keep plates fixed axially with the roll neck. Immediately under the keep plates in the case of the top roll (or over them in the case of the bottom roll) the water-spray pipes were introduced from a new distribution system. As this spray water is the only means of lubrication and cooling, the original grease and water piping was redundant. Owing to difficulties in moulding, the bearing liners and the bearing thrust collars have to be in separate pieces.

The scale guard for the bottom neck on the drive or first-pass side is now made by having a moulded sealing ring which is bolted to the chock keep and presses against the thrust-collar face of the roll. This sealing ring is then covered by greasy packing, and the whole assembly is covered by a neatly fitting curved plate, which is also attached to the bottom-chock keep.

As was to be expected in an innovation of this kind a series of troubles occurred, but these were gradually overcome and the lessons learned.

Firstly, it is absolutely essential to have a copious supply of clean or, if necessary, filtered water at such a pressure that the water film at the intake side of the roll neck is sustained. This water also acts in a large measure as a preventative to ingress of grit and foreign matter to the rubbing surfaces by washing it away. A pressure of 25-30 lb./sq. in. has been found to be quite satisfactory.

Secondly, it was found that a slight deposit of rust on the roll necks (such as would form in, say, 4 hr. and over with the rolls at rest and the water turned off) would be sufficient to cause abrasion of the fabric bearings. It was also found that the surface in contact with the bearing rusted quicker than that part of the roll-neck surface exposed to the atmosphere.

The elimination of these films of rust was a problem on which a series of experiments was carried out. It was found that for short delays in the rolling programme (such as heat shortages and the like) it is better that the rolls be kept revolving, with the water supply running normally. For a delay of a few hours, when it would be expensive to keep the rolls running, coating the roll necks with thick lubricating oil just before they came to rest and with the water turned off was tried. This gave a certain amount of protection, but was not a guaranteed preventative against a rust film.

It was, and still is, the mill greaser's responsibility to see that no rust films form on the roll necks.

During the war, and as a result of research into the fields of de-watering, rust prevention, and the

cleaning of machines which had been submerged owing to enemy action, a new oil was evolved. As our problem was well known to the people carrying out this research, we were able to obtain some of this oil. The results were highly successful, and the problem of rust-film prevention now appears to have been solved.

For storage purposes the roll necks are now treated with this same oil, which preserves them in the open air for periods of up to six months. It should be mentioned here that in the early days, when rolls in storage had their necks dried, cleaned, and treated with a protective covering, a very fine pitting was prone to take place. This pitting could be removed successfully only by grinding the roll necks. As this was a laborious process, polishing with emery cloth was tried, but the results were not altogether a success and the method by no means answered as an alternative to grinding. It will be readily appreciated that these pit marks had a very bad effect on the fabric bearings, causing extremely rapid wear.

Thirdly, the destruction of the bottom-roll bearings owing to scale getting on to the rubbing surfaces caused some trouble, but the arrangement previously described has improved matters, although the scale guards must receive constant attention and must be kept up to the highest possible standard.

The bottom-roll bearing on the heavy or drive side is the one that suffers the greatest punishment. This is the side on which the ingots first enter the mill. A bearing in this position gives only about 100,000 tons of rolling life.

Contrary to expectations, the next bearing to suffer is the top light side. One would have expected the top heavy side, or even the bottom light side, to show more wear than the top light side, but this is not so in practice. The reason for this is doubtless owing to the fact that the finished bars pass out of the mill on the light side. This means that the light-side bearings are more heavily loaded than the heavy-side bearings for the final passes. Further, the bars being longer, the sustained runs are greater, and the water film must be of such intensity that it will keep the whole surface of the bearing wetted when entering from only one side under these harder conditions.

In comparing the top bearing with the bottom bearing it will be noted that the water film on the former has to be carried into the bearing against gravity, whereas in the case of the latter it is with the aid of gravity.

III—COSTS AND A FEW COMPARISONS

As the light-section mill is engaged in rolling so many different sections and the bearings are used

with many different rolls, it is extremely difficult to obtain reliable figures regarding the individual performance of any bearing. The following figures are based, therefore, on the results obtained in the blooming mill, where conditions are such that the performance of each bearing can be carefully noted and records made of the individual tonnage outputs.

All the bearings in the blooming mill are 1 in. thick when new and are worked until their thickness is not less than $\frac{1}{4}$ in. As far as is possible, all changes of bearings are made at the week-end.

(a) *Conversion of Blooming Mill from Bronze to Synthetic-Resin Bearings*

As previously stated the chocks of the blooming mill were the only major parts needing modification, although a new water-distribution system had to be provided, which accounted for a fairly substantial part of the total cost of conversion. The costs were made up as follows:

Modification to existing chocks and supply of all new parts, piping, filters, etc. ...	£460*
Supply of 1 set of synthetic-resin bearings, collars, and seal rings	£240
Total	£700

* Approximate figure.

The cost of a set of bronze bearings in 1937 was £325, hence we could expect to save £85 in the cost of the renewable or wearing parts. Actually, the cost of a complete set of synthetic-resin bearings today is £235, showing a decrease of £5, which is doubtless due to improved methods of manufacture.

From the bronze bearings we could expect an individual bearing life of anything up to 11 months, working on a two-shift basis, whereas from synthetic-resin bearings we have obtained an individual bearing life of up to 30 months, working on a three-shift basis.

From figures to be given later it will be seen that a saving of up to 19% in power consumption can be obtained by the use of synthetic-resin bearings.

(b) *Maintenance*

With regard to maintenance, it has been the practice to change bearings and collars as far as possible at week-ends, when rolls were being changed; failures of bearings have, however, occasionally made it necessary to change them during the working part of the week. To do this occupies approximately 1 hr. for a light-side synthetic-resin bearing and 1½ hr. for a heavy-side synthetic-resin bearing, and the work involved

occupies two fitters, two helpers, and one slinger, a total of five men.

In order to compare this with the work involved in changing bronze bearings, it can be said that the same number of men would require 5 hr. for a light-side bearing and a somewhat longer period for a heavy-side bearing.

(c) *Lubrication*

To lubricate the bronze bearings it was necessary to feed into the mechanical grease pumps $\frac{1}{2}$ –1 ton of grease per week, at a cost of £33 per ton pre-war, or at today's price, £48 per ton. This would be 50% more in the case of the present three-shift operation. The whole of this cost is saved by the use of fabric bearings, but there is a charge for protective oil which amounts to approximately £1 per week.

(d) *Water Supply*

The water supply to the bearings is filtered

through a twin strainer having a straining mesh of $\frac{1}{16}$ -in. dia. holes, and is drawn from a nearby dock; the water therefore contains a certain amount of foreign matter, and, although the dock is fed by a fresh-water feeder, the operation of the locks to allow ships to pass in and out of the dock permits a certain amount of contamination by tidal water. This contamination varies very much with the volume of shipping and has increased during the war. In general, the water is of the type which any industrial concern would use for cooling purposes in great volume.

The quantity of water used for roll cooling is approximately 200 gal./min.; this figure includes that used for roll-barrel and neck sprays. No separate measurements have been made to determine the exact quantity used on the roll bearings only. As all the water used is returned to the dock, and as the separation of bearing-cooling water appears to be an impracticable

TABLE I—*Comparative Power Consumptions with Bronze and Moulded Synthetic-Resin Bearings*

Bronze Bearings				Moulded Synthetic-Resin Bearings			
Week Ending	Tons Rolled	Units Consumed	Units per Ton	Four Weeks Ending	Tons Rolled	Units Consumed	Units per Ton
6/11/37	6,449	139,420	21.6	26/1/46	41,419	757,860	18.3
13/11/37	6,771	146,150	21.6	23/2/46	41,354	709,080	17.1
20/11/37	8,365	165,630	19.8	23/3/46	47,407	785,250	16.5
27/11/37	6,869	152,940	22.3	20/4/46	46,919	777,250	16.5
4/12/37	8,036	158,130	19.7	18/5/46	45,982	774,410	16.8
11/12/37	7,935	163,390	20.6	15/6/46	41,002	696,560	16.9
...	...	...	...	13/7/46	46,891	788,240	16.8
Total ...	44,425	925,660	125.6	Total ...	310,974	5,288,650	118.9
Average ...	7,404	154,277	20.93	Average ...	44,425	755,521	17.0

TABLE II—*Power Consumption on Mill Motor during 25th November, 1946*

Number of Ingots Rolled	Ingot Weight		Total Ingot Weight		Passes Per Ingot	Total Passes	Type of Section Rolled	Size of Section, in.	Power Consumption, units	Power Consumption, units/ton of product
	Tons	Cwt.	Tons	Cwt.						
28	3	15	105	0	16	448	Sheet bar	12 × 2	1,700	16.2
15	3	18	58	10	19	285	Blooms	5 × 5	1,000	17.1
13	3	18	50	14	19	247	Blooms	5 × 5	900	17.7
23	3	18	89	14	19	437	Blooms	5 × 5	1,500	16.7
23	3	18	89	14	19	437	Blooms	5 × 5	1,500	16.7
27	3	18	105	6	19	513	Blooms	5 × 5	1,700	16.1
15	3	18	58	10	21	315	Blooms	5 × 6	1,200	14.6
6	3	18	23	8	19	114	Blooms	5 × 5		
16	3	18	62	8	19	304	Blooms	5 × 5		
12	3	11	42	12	21	252	Blooms	5 × 6		

proposition, the question of using soluble oil and recirculating has so far been ruled out.

The continuity of the water supply is absolutely essential, because the bearings would burn out should it fail for even a matter of seconds. To ensure that the mill is not worked with the water supply below normal, two pressure-gauges have been fitted up on a panel immediately in front of the mill driver. One gauge shows the pressure of the water going to the heavy-side bearings and the other the pressure of water going to the light-side bearings. The connections for these gauges are made as near to the mill as possible.

OIL-FILM-TYPE BEARINGS

*By G. R. Walshaw**

THE Company with which I am associated uses many types and sizes of roll-neck bearings in their section and plate mills, but this paper will be concerned only with the sleeve type of bearing using oil-film lubrication, as installed on the finishing stand of the 7-ft. plate mill at Appleby-Frodingham.

THE MILL, ROLLS, BEARINGS, AND PRODUCT

Briefly, the mill is a four-high mill, made by Sack of Dusseldorf but equipped with bearings of the Morgoil type, made by the Morgan Construction Company of Worcester, Massachusetts. The mill motor is of 5000 h.p. (R.M.S. rating), and has a speed of from zero to 120 r.p.m. in each direction, with a maximum acceleration of from zero to 60 r.p.m. in 1 sec.

The top and bottom backing rolls are of cast steel, 48 in. in dia. and 7 ft. 3 in. long in the barrel, and the work rolls are of chilled iron, 26 in. in dia. and 7 ft. 3 in. long. The work rolls run on grease-lubricated white-metal bearings, but as the whole of the rolling pressure comes on to the backing-roll bearings these are the only ones which will be dealt with here. The backing rolls have tapered necks, 30½ in. in dia. at the large end and 25⅝ in. in dia. at the small end, on which the sleeves containing the bearings proper are mounted (see Fig. 1). The sleeves are pushed on to the tapered necks and secured by means of a screwed nut engaging with a split screwed collar let into a recess turned in the end of the roll neck, the diameter of the bottom of the recess being 23 in. The actual journal bearing is 34 in. in dia. and 30½ in. long, giving a projected area of 1037 sq. in. The speeds of the backing rolls average 31 r.p.m., with a maximum of 65 r.p.m.

IV—POWER CONSUMPTION

Typical figures for power consumption at the Cardiff works are given in Tables I and II. From Table I, which shows the power consumption when using bronze and when using synthetic-resin bearings, it will be seen that a power saving of 19% was achieved by the use of synthetic-resin bearings. Typical power-consumption data for the 6650-h.p., zero to 150-r.p.m. mill motor are given in Table II. The ingot size is 21½ in. × 21½ in., tapering to 19½ in. × 19½ in., and the approximate length is 6 ft.

With regard to the roll pressures on this mill, no actual readings have been taken, but the figures given by the designers are :

Maximum load per roll neck	...	...	500 tons
Average load per roll neck	...	...	300 tons
Maximum load per square inch of bearing area	...	...	1080 lb.

As mentioned, the bearings are of the Morgoil type, and they are lubricated by a continuous supply of oil pumped from the receiving tanks through a mechanical filter filled with small metal ferrules. The bearings are secured in the housing chocks by means of a large flanged cap at the outer end, with an adjustable screwed flange, inside the cap, bearing against the thrust collar of the main sleeve. At the end of each bearing is an oil-seal ring and at the end next to the barrel of the roll is also a water-seal ring, bearing against the shoulder of the roll, the purpose of which is to exclude the water and scale coming from the roll barrel.

The slabs for this mill are roughed-down in a preceding roughing mill to a thickness of ¾–1¼ in. before passing along the roller tables, without further heating, to be finished in the finishing stand just described. The weights of plates rolled vary from as low as 6 cwt. up to 3¼ tons. The finished thicknesses range from ¾ in. down to 0.109 in., and the widths from 84 in. downwards. The most usual lower limit of thickness is ⅙ (0.125) in.

When ordering this mill in 1938 the Company had in mind the production of hot-rolled plates with a high standard of finish and a sustained accuracy of gauge as could only be equalled by a hot-strip mill. The Morgoil type of bearings had been seen in use and in process of being manufactured, and were actually being employed with success in the 12-in. hot-strip mill at one of our associated works. The manufacturers of the mill recommended their own design of white-metal bearings, and fabric bearings were also

* Appleby-Frodingham Steel Co., Ltd.

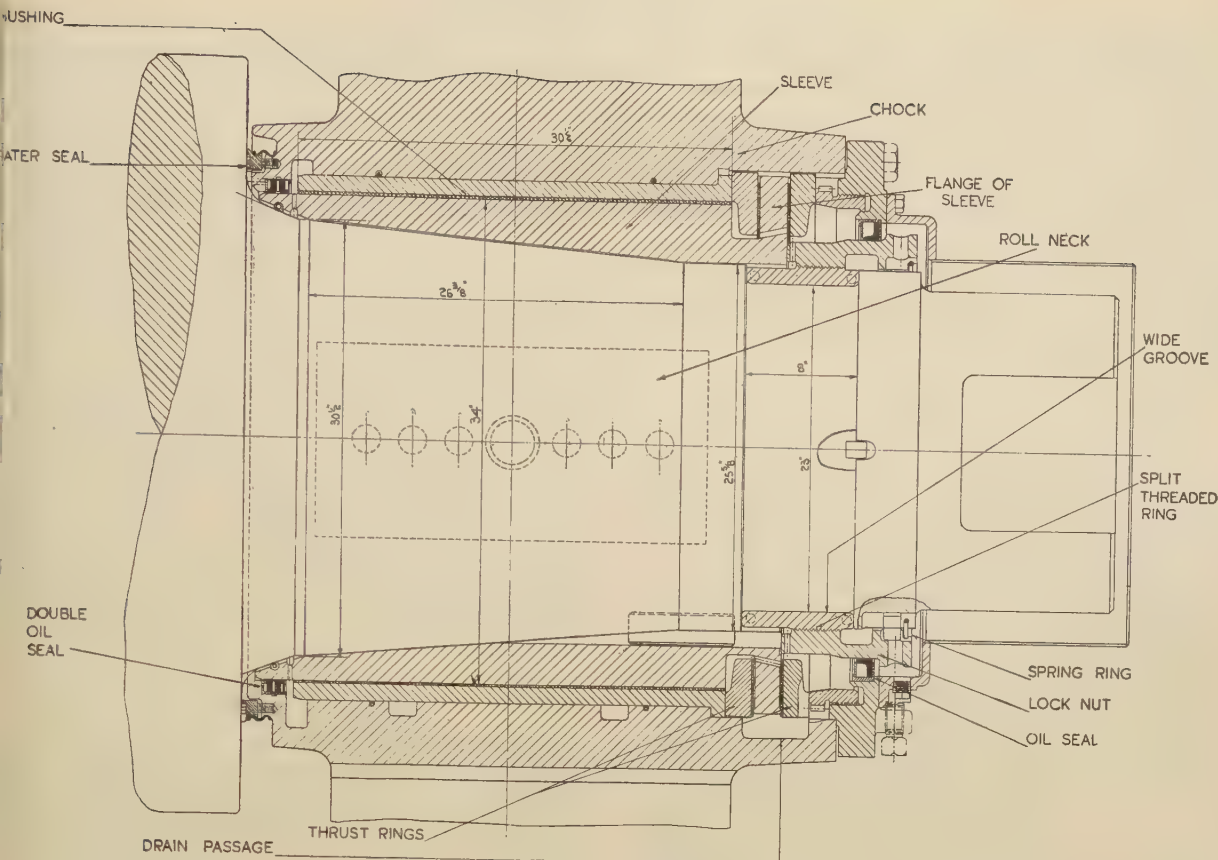


FIG. 1—Cross-section of typical Morgan roll-neck bearing

considered, but doubt was felt as to their giving the good results desired.

Maintenance

With working rolls which are in good condition there is very little or no variation in gauge across the width. Only three changes of bearings have been made from October 1939 to November 1946, and the finished-plate output of this mill in that period has totalled 631,790 tons. The original bearings ran 109 weeks and gave an output of 190,000 tons. By then the wear on the bearings had begun to affect the efficiency of the oil seals, causing a loss of oil, so the spare set of bearings which had been supplied with the mill were put into service in December 1941. These bearings ran 78 weeks (until July 1943), and gave an output of 135,455 tons.

As careful examination of the original set of bearings taken out in 1941 revealed that their life was not exhausted, it was decided to turn the bearing sleeves round from top to bottom and run them again. This was done in July 1943, and the bearings ran until July 1945—a total of 105 weeks, the output being 186,748 tons. The

total life of this original set, without re-metalling, was thus 214 weeks and the total output over 370,000 tons. At the original cost of £4,729, this works out at 3d. per ton of output.

In the meantime—as during the war it had not been possible in this country to re-metal the worn bearing shells—a further set of bearing metal-lined shells and thrust rings was procured from the makers, and these have run from then until the 2nd November of this year—a total of 65 weeks. The output for this period was 119,577 tons, and the bearing shells and thrust rings are still in operation. The worn shells taken out have been re-metalled and we now have two sets in stock as well as those in use. As the cost of installation was included in the cost of the installation of the housings, no separate cost can be given for this item.

The backing rolls are changed about every six to nine months for the regrinding of the barrel surfaces, and this involves changing the bearings from the worn rolls to fresh rolls; this operation takes about 30 hr. at the week-end.

The most frequent item of maintenance is the renewal of the oil- and water-seal rings. Neglect

of these leads to excessive oil consumption and to contamination of the oil by water from the roll barrels. To guard against this the oil is analysed each week for water and dirt content and the results give a clear indication of the conditions of the seal rings, although no means have so far been found to indicate from which seal the leak takes place when this is of a minor character. The life of the oil seals varies very much, ranging from as little as two months to up to six months. About 8 hr. are required to change a set of seals on one bearing.

Costs

The present-day cost of a complete set of four sleeve rings lined with metal, and eight thrust collars, is £1200 or £300 per bearing, whilst the cost of re-metalling a full set (which can now be done in this country) is a little over £1000.

To sum up the costs entailed by using Morgoil bearings on this mill, it can be stated that the capital cost of the first two complete sets, supplied with the mill at a cost of £9460, spread over the seven years since the installation of the mill, works out at 3.6*d.* per ton. This is a diminishing figure, because there are many years of life left in the bulk of the material supplied. The maintenance cost, which includes all renewals of every sort and all labour and also includes some other items which cannot be separated, has amounted to £12,450 in seven full years, equal to 4.73*d.* per ton. This includes repairs to the screws, the chocks, the pipes, and anything else on the housings, except the work-roll bearings. The oil consumption—which will be discussed later—amounts to 2.34*d.* per ton. In view of the excellent results achieved, these cannot be considered high figures.

As regards oil consumption, the oil system supplies both the roll bearings and the pinions, and the amount in service is about 1600–1800 gal. There are two tanks, which are used alternately week by week, and whilst one tank is in use the oil in the other tank is being settled and the water—if any—drained off. The oil is then passed through a centrifuge, to extract the finer particles not settled-out in the tank. The tank in use is steam-heated, and an endeavour is made to maintain the temperature of the oil in service at from 90 to 100° F.

The properties of the oil, which is a straight mineral oil, are as follows :

Viscosity (Seybolt at 100° F.)	...	1500–2000 sec.
Flash-point minimum	...	400° F.
Emulsibility (Herschel test)	...	1200 sec. at 130° F.
Pour point	...	<35° F.

The minimum quantity supplied to each bearing is not less than 5 gal./min., and the pressure at the bearing is maintained from 10 to 15 lb. per sq. in. The make-up oil amounts each year to 120 barrels. This is considered to be on the high side, but it includes losses from the pinions, evaporation from the tanks, and a certain amount lost each time the work-roll bearing are changed (three times per week), when the oil pipes have perforce to be disconnected. The oil-consumption costs amount to 2.1–3*d.* per ton of output.

The power consumption varies, as might be expected, according to the width and thickness of the plates being rolled, but detailed figures for any particular thickness are not available. An average power consumption, calculated from the power input to the Ilgner set and the total tonnage over the last eleven months, is 36½ units per ton. This figure excludes exciter sets and other auxiliaries and also the units used during idle running times, *e.g.*, during meal times.

ACKNOWLEDGMENTS

The author wishes to express his thanks to the Management of the Appleby-Frodingham Steel Co., Ltd., for permission to publish the data contained in this paper, and also to his colleagues for their help in collecting the information.

DISCUSSION

The **Chairman** : We have listened to four very interesting papers. It is a great pity that they could not be printed beforehand, because we have heard so much in such a short time that it is difficult to remember everything that has been said.

Mr. **J. S. Mayne** (Davy and United Engineering Co., Ltd.) : I agree that we have listened to four very instructive papers given by men of experience in their own spheres of operation. I was particularly interested in the fabric bearing dealt with by Mr. Jones, having myself tried to develop this type of bearing somewhat on the lines of the fluid-film bearing, with a view to enclosing it altogether so as to keep scale and other foreign matter out of the bearing and to ascertain whether this idea could be made into a practicable proposition.

There were certain difficulties to surmount. The fact that these bearings have considerable life and that they can wear down from about $\frac{7}{8}$ in. to less than $\frac{1}{4}$ in. makes the sealing very difficult to achieve. During our investigations however, we found an effective means of performing this sealing.

Mr. Jones told us that his Company used dock water for cooling purposes. There was one case in Staffordshire some years ago where canal water was used and the bearing lasted one day. Can Mr. Jones tell us whether any better results would be obtained if town water were used? The results so far are very good but would they be even better if town water were used, possibly in a closed-circuit installation?

Another point is the manufacture of the bearing linings. There are four ways of making them, one from random clippings, this method being used on smaller bearings that are moulded to shape, say, for use in 15–21-in. mills. The bearings can also be made from blocks, in which case they do not always give the same surface characteristics throughout the width and length of the bearings. The most common method is to mould them to shape from sheet fabric, and the fourth method is to cut them from tubes. Can Mr. Jones tell us whether he has any experience or knowledge from which to make the comparisons between these four methods?

With regard to the other types of bearings, it was very interesting to hear from Mr. Pearson of the way in which roller bearings are passed from one mill to another to get the best of life from them. Far-sightedness was shown in making all the bearings alike for the full range of mills so that this can be done.

My firm is interested in fluid-film bearings, having installed them on many four-high mills, and it was very interesting to learn from Mr. Walshaw of the success of the Morgoil bearings he referred to, particularly how the original bearings have been turned round and used again. It will also be of interest to know the total tonnage that has been rolled when they are eventually taken out.

The Chairman: Have you used anything but moulded ones, Mr. Jones?

Mr. F. W. Jones: We use only the straight moulded ones. We tried some machined from moulded blocks, but they are no use.

Mr. W. P. Snedden (British Timken, Ltd.): Yesterday in Birmingham everybody was in a fog; we could not see where we were going. Today in London, with the aid of artificial light, we all know where we are going, especially from the point of view of bearings. I have listened with great interest to the four speakers who opened the discussion. They spoke of various bearings which are all, no doubt, good in some way when they are applied to roll necks and applied to the types of mill for which they are suitable. I think that Mr. Pearson mentioned that I am

particularly interested in the roller bearing, and especially in the taper type of roller bearing. He also mentioned that the Morgoil bearing was a very keen competitor of the roller bearing.

The Morgoil bearing came into the field later than the roller bearing, and the attitude seemed to be that here was something later and therefore better. I am not going to say that steelworks engineers follow fashion in every way, but I am afraid that they do tend to do so. There is no doubt that the Morgoil bearing came later and is a good bearing, but it has never been proved that it is a better bearing than the taper roller bearing. To show how fashions go, you will all recall the publication called "The Modern Strip Mill," of which some received a copy from America. That publication showed certain tables giving various mills using the roller bearing and the Morgoil bearing, and it looked as though the roller bearing had had its day; but, if you must look to America, let me say that last year, out of 93 stands of mills built in that year (1945), 93 had taper roller bearings at least on some of the roll necks, and 49 were completely equipped with taper roller bearings on the main or back-up-roll necks. There were 22 equipped with Morgoil bearings and 10 with Mesta oil-sleeve bearings. That was the fashion last year.

You want to hear something of what the roller-bearing manufacturers are doing to meet the demand for a bigger neck. Repeatedly when I used to go to mill engineers, and especially to the old-fashioned mill engineers, I found that the rule they worked to was 0.6 of the barrel diameter for the neck, irrespective of whether it was necessary or not. I do not remember putting a bearing on a roll neck where I lost the roll neck through weakness, and no roller-bearing manufacturer of repute would do so; but to satisfy the demand for the strongest possible roll neck the designers and manufacturers of the Timken Bearing Company in America decided to give the steel men their wish, a bigger roll neck. We therefore developed the "balanced-proportion" type of bearing.

The name does not mean much. It means that the proportion or balance of existing bearings has been altered in order to give a maximum capacity for a roll-neck diameter, retaining the outside diameter of the bearing as small as possible. The only way in which you can do that is by using a smaller roll in the bearing, but the roll must also be longer, and that is all that has happened—nothing more and nothing less. I do not advise you to consider too small a roll or too long a roll, but this bearing has now been applied to several mills. The only slabbing mill in the world equipped with roller bearings has worked on it

for three years ; the bearings were looked at once and found to be doing a splendid job.

The whole idea of balanced-proportion bearings arose from the performance of 110-in. and 120-in. wide strip mills, a study of which brought forward the balanced-proportion idea ; it was owing to the success of those roller bearings in these heavy mills that it was decided they ought to be put on slabbing mills as well, because it was felt they would show the most favourable cost compared with any other type of bearing that could be put on a slabbing or a blooming mill, and this looks like being proved. It is certain that the taper roller bearing holds the world's record from the point of view of cost per ton rolled, and it is approximately 0.001*d*. When you get to the second nought, you can forget the rest !

I must also point out that with fabric bearings and with white-metal bearings it will always be found that to cater for the thrust is a difficult problem. You get it again in the oil-sleeve bearing. Unfortunately, we have not yet built any mills without thrust, though I suppose the day will come when that may be attempted. As long as the thrust is there you have to cater for it, and it is little use to have an oil-sleeve bearing which is performing magnificently radially if you are constantly changing the thrust unit at the end of it. So much is that the case that, with the exception of Bethlehem at Lackawanna, there are no Mesta mills in the whole of America working without taper roller bearings taking the thrust, so that you have a combination of two bearings doing the job of one, which is not very clever from an engineering point of view.

I do not wish to dwell too long on bearings, but I do wish to point out this instance of what I mean by balanced-proportion bearings. Several years ago we equipped a two-high bar mill in the Detroit district with bearings of the following dimensions :

Outside diameter	...	...	...	16 $\frac{3}{8}$ in.
Bore	...	...	...	10 $\frac{1}{4}$ in.
Width of bearing	...	...	...	12 $\frac{1}{2}$ in.

The radial rating was 228,000 lb. at 100 r.p.m., for bar-mill use. Today that bearing would be replaced in a similar-sized mill by one with a bore of 11 $\frac{13}{16}$ in., the same outside diameter (16 $\frac{3}{8}$ in.), and with a width of 12 $\frac{1}{4}$ in. ; the width has been cut down by $\frac{1}{4}$ in. by using a different type of roll. It has a radial rating of 310,000 lb. at 100 r.p.m. That simply means that you can get an increase of 36% on the bearing capacity. The bore is 15% larger and consequently your neck stress goes down 36%. You have that extra life built into that bearing, which is 2.83 times the life of the

original bearing, which has already given a very good account of itself in practice. That is what balanced proportion means—to get the maximum bearing capacity with the largest possible bore and the smallest possible outside diameter, with a very closely guided roll. We are willing to do it here, but do not come to us for balanced-proportion bearings to be incorporated in mills without any modifications, because they will not go into your existing mills anyhow. The reason for the extra life is that the life of a roller bearing is really in the cubic inverse ratio to the load that it carries. That is why the extra life comes away up to the figure of 2.83.

As regards the oil-film bearing, I do not know whether you are all aware of what is involved, but when an oil-film bearing breaks down you invariably lose not only the shell but the sleeve itself, and you get that frequently with roll breakage. We can get a roller bearing to withstand roll breakage in a mill on many occasions, though not always. In the oil bearing you have five seals to maintain, as against two with a normal roller bearing, and any of you who know anything about seals know what you are up against there. If you supply real maintenance, it may be necessary to check the clearance enclosures probably as many as four times a year with an oil-sleeve bearing, and in a continuous-strip mill operating continuously it is very difficult to say what happens when the moisture content of the oil rises above 4%. I happen to know that it sometimes causes considerable trouble.

I have never seen a taper roller bearing stand still when the mill started up, but I have seen oil-sleeve bearings stand still, causing flats on the roll barrel and the redressing of a very expensive roll. As we all know, you must of course maintain an oil circuit continuously to an oil-sleeve bearing, and that means plenty of piping. You have to carry the piping either under the tables and over the mill housings, perhaps round the end of the chocks. I do not think that that is the type of thing that you want in a steel mill, especially when changing rolls. A bearing should be easy of assembly and easy of removal.

You have not only to use your oil and maintain it there, but you must also circulate it, and the cost of circulation comes in. You must have motors running and pipelines to maintain, and when you change a bearing you will probably lose 5–10 gal. of oil on a big bearing every time you change it. You can never start an oil-film mill until the proper pressure of the oil has been reached, or you will be in trouble, and so you have to wait until the pump builds up the oil pressure before you can begin to operate. You have a

film of oil, say, 0.006 or 0.007 in. thick, and that is what you have to roll on. You can roll on it so long as it is there, but the moment it has gone you cease to roll—and you cease to have a bearing.

A roller bearing theoretically does not need lubrication, but it does of necessity operate practically with a lubricant. You may like to know, however, that only recently we had a case of a bearing that operated for three days without any oil in it. It worked with no oil at all because of neglect of the operators to fill the chock, but please do not try to repeat this; bearings must be lubricated.

Mr. L. D. Colam (Farvalube, Ltd.): Mr. Borland made the statement that the twin-line pumping system of lubrication was prone to air locks. I should like to state that in any type, whether twin-line or single-line, if air is allowed to get into the pipes in the original filling trouble is bound to occur. In what I think is the particular installation which Mr. Borland has in mind, a very unfortunate accident occurred whereby an air-operated pump, used to transfer the lubricant from the barrel to the system and which was no part of the system, was allowed to pump the barrel dry and went on pumping air into the system.

Captain C. A. Ablett (Cooper Roller Bearings, Ltd.): I should like to recall to you a Carnegie Scholarship Memoir presented to this Institute in 1910 by Dr. Puppe. In that memoir Dr. Puppe showed that the power lost in a cogging mill is 37% of the power supplied. Now let us apply that figure to a rolling mill with which I had something to do, namely, the original electrically driven 36-in. cogging mill at Skinningrove. That mill was driven by a 12,000-h.p. motor, ranging up to 18,000 h.p. If we had been able to get rid of all that 37% of friction, that motor might have been of 8,000 h.p. Look at the saving in capital cost, and look at the target at which we have to aim! I do not suggest for a moment that the 37% loss of power is in roll-neck bearings; it is in pinions, pinion necks, wobblers, and so forth, and I do not think that pinions have been mentioned today.

Dr. Puppe produced another very interesting paper, which unfortunately has never been translated into English. It was read before the Verein Deutscher Eisenhüttenleute and is concerned with section mills. Those of you who read German would find it of great interest.

As a roller-bearing manufacturer, I should like to deal with one or two points which have come up in this discussion. I am accustomed to think of heavily loaded roller bearings running for 20–30 years and still running, and it comes a surprise to me to see Mr. Pearson's figures, showing a com-

paratively short life. When we see the slides which were shown the reason becomes apparent—too complicated a design of the roller bearing. I expect you all have a copy of the book called "Roll Neck Bearings" published by the British Iron and Steel Research Association. I should like to refer to a diagram which appears on page 195 of that book, showing a bearing of very simple design for a cogging mill, working under conditions and of a size very much like the bearings put on the trunnions of 16-in. naval guns. That design will repay a little study. It has been said in this discussion that if you change the rolls you have to change the bearings with them. If you look at this design on page 195 you will find that you do not have to change the bearings with the rolls; you change only the inner race.

There is another point which has been raised on which I join issue with the speaker, and that is the statement that the life of a roller bearing is limited to the inverse of the cube root of the loading. If you design bearings properly and select a suitable loading, I do not think that there is any limit.

Mr. J. R. Widdowson (Messrs. Samuel Fox & Co., Ltd.): Many remarkable figures have been given us today in connection with tonnages rolled on various types of bearings, but I think that each type of bearing has its own application. If you consider a jobbing mill where the rolls have to be changed two or three times a day, it would be very difficult to use roller bearings, as the roll-changing time would be much greater than with other types of bearings.

We have a mill of this type which has been running many years with brass bearings, and an attempt was made to adopt fabric bearings. This meant that all the roll necks required turning and grinding, and, because of previous wear, the neck sizes had to be graded in order to accommodate approximately four sizes of fabric bearings. Up to the present time we have not experienced a great deal of success, the difficulty in the roughing stand being due to scale entering the bearings and the wearing fabric; also, it is not easy to educate the rolling-mill teams to this new type of bearing when they have been using brass for so many years. There is usually difficulty with water-spray pipes when changing rolls. These seem to be easily damaged, and the water supply fails.

Does Mr. Jones consider, when converting from brass to fabric bearings, that it is necessary to keep some independent person to watch the mill for a considerable time, until the rollers have been educated to this new technique?

With regard to roller bearings, has Captain

Ablett experienced any creep between the roller bearing and the roll neck? In most cases clearance is allowed between the bearing and roll neck, but there is again the difficulty of lubrication between the roll neck and bearing. Can he tell us what his experience has been in connection with this, and also has he ever experienced any appreciable wear of the roll neck?

Mr. F. W. Jones: It is very difficult to answer the last speaker's question as to whether he should change his bearings first and then educate his operatives, or whether he should first educate his operatives and then change his bearings.

It seems to me that the best answer would be that he should (a) train his operatives to look upon synthetic-resin bearings as a scientific piece of apparatus, (b) let his operatives handle synthetic-resin bearings and see the uses and advantages of them, (c) train these operatives outside their actual work, but inside their working hours, and (d), having got the men thoroughly conversant with the new type of bearing then instal the bearings.

He will find that his operatives will take a greater interest in synthetic-resin bearings than they now do in brass bearings.

Mr. L. R. Pearson: The question has been raised of the clearance between the neck and the bearings, *i.e.*, whether we experience creep between the inner race of the bearing and the roll neck.

We do, and definite clearances are allowed to permit ease of assembly of the complete units—bearings and chocks—on to the roll necks. Generally, it is desirable to leave 0.006–0.010 in. clearance on a 25½-in. roller bearing and provide adequately for lubrication at that spot. This is a point on which I did not touch in my paper because time was limited, but it is a very critical feature of the application of these bearings to four-high mills, and it is a problem which we are now satisfactorily solving by means of drilling the roll necks and applying lubrication direct to that point from our central automatic system.

Reference has also been made to the life of roller bearings. I must leave it to the bearing makers to take up the cudgels on that point, but generally I would say that you will not get any large bearing maker to talk of anything greater than a life of 20,000 hr. for a five-stand cold-reduction mill rolling down to tinplate gauge and at present-day high speeds. If you get 20,000 hr. you can get up to 2,000,000 tons by combination rolling, that is, by passing them on to a hot-strip mill using the same size bearing. With new bearings direct in to a hot-strip mill, tonnages of around 3,000,000 could be expected, except in those isolated cases where severe “wrecks” have taken place in the mill.

Mr. W. P. Snedden: The figure of 20,000 hr. mentioned by Mr. Pearson relates to the heaviest-loaded mill in Britain today. I have had roller bearings operating for 14 years non-stop in a mill in Birmingham which has worked three shifts almost from the day when it was installed. It is a cluster-mill rolling duralumin.

Captain C. A. Ablett: The question of changing rolls on a section mill has been mentioned. You will find the answer to that question in another industry, the wallpaper printing industry. It is on a much smaller scale of course, but the principle is the same.

Mr. C. S. Clarke (Skefko Ball Bearing Co., Ltd.): The question of roll changing has already been answered by the roller-bearing manufacturers. It is a fact that the time taken to change rolls with roller bearings is very little, if any, more than with plain bearings. It is entirely a question of design. As Mr. Pearson has said, in the large mills at Ebbw Vale a loose fit is provided between the inner rings of the bearings and the roll necks, so as to admit of the bearings with the chocks being readily withdrawn from the roll necks. In some large mills we use a different design whereby the bearings are made a press fit on the necks. This obviates the necessity for specially lubricating the roll necks. Such bearings fit on taper necks or on taper sleeves, the sleeves being readily withdrawable and, of course, the bearings being quite easily forced off the taper necks. For smaller section mills, where quick roll changing is of paramount importance owing to very frequent change in sections, the loose mounting retains its popularity, providing as it does a very rapid roll change, but even in these mills the taper mounting has much to commend it, including a stronger roll neck, and is now being more widely adopted.

One point which has not been mentioned in this discussion with regard to roll-neck bearings is the accuracy of the finished product. In small section mills this is of extreme importance, and there I think the roller bearing definitely has an advantage over all other bearings, providing as it does very accurate adjustment of the rolls. What is more, the roller bearing enables that accuracy to be maintained, so that with a roller-bearing mill a very much better product is obtained, and, what is more important, also a smaller percentage of scrap. It is claimed for finishing mills that this improved and increased production comes first in the list of advantages to be derived from using roller bearings.

Our company have recently developed a very fine wire mill, eliminating the frames or housings and preloading the chocks of the mill in such a way

that it is possible to eliminate almost all the deflection in the rolls. This mill, with rolls of 13 in. dia., has been running for about six months, and, because the stand, complete with guides, etc., can be taken out and replaced complete, a roll change can be made in less than 5 min. The replaced stand then goes into the fitters' shop, where the rolls are dressed and the stand is refitted and adjusted.

I think Mr. Snedden has fully replied to Mr. Borland on his statement of not being able to introduce roller bearings without unduly reducing, and therefore weakening, the roll necks. Roll-neck breakages are practically unknown with roller bearings, despite the fact that the diameter of the neck may be slightly less than in the case of plain bearings. Our company have quite a number of blooming mills working on roller bearings, and in our own steelworks we have had one two-stand 32-in. mill in service for over 10 years, and the original bearings are still in use. It is a comparatively small production mill dealing with special steels, and has rolled about 1,000,000 tons in that time, but on the last occasion when the bearings came out for examination they were found to be in perfect condition.

Mr. J. M. Borland: The balanced-proportion bearing mentioned by Mr. Snedden is a very interesting development, and its operating performance will be closely watched. In reply to Mr. Colam, I was not referring to the incident which he mentions. In the twin-line system difficulty is experienced with the heavier classes of grease, owing to cavitation of the grease around the pumping unit in the grease reservoir, and, owing to the very short stroke of the pump plunger, a small cavity is sufficient to stop the grease being pumped.

Mr. R. L. Willott (Messrs. John Summers and Sons, Ltd.): Manufacturing champions of most types of mill bearing appear to be present today, but, outside of Mr. Walshaw's remarks in his paper, little specific comment has been made on oil-film operation. Since hot and cold Mesta strip mills and a Mesta slabbing mill have been in continuous operation at Shotton since 1939, some record of our experience may be of interest.

Back-up rolls, as originally installed, are mounted in standard Mesta oil-film bearings. Work rolls run in roller bearings. I speak therefore as a user of both and champion of neither.

With regard to bearing failure, in six years, during which we have rolled 2,000,000–3,000,000 tons in the continuous hot mill, we have no recorded case of back-up-bearing failure. A number of back-up rolls have broken through the neck, within the bearing, but this has not resulted

in bearing failure. Our experience with work-roll roller bearings is not greatly different; some of these bearings have rolled over 1,000,000 tons and are still in service.

With the exception of No. 1 stand of the hot mill, all our stands are identical and, in consequence, back-up rolls and bearings do universal service. Comparing our results with the figures given for the Ebbw Vale plant by Mr. Pearson, our operating results appear to run closely parallel, which rather puts the two types of bearing on a similar footing for strip-mill service.

Our strip-mill back-up rolls have the normal shrunk-on Mesta taper sleeve, and these have proved entirely satisfactory. The taper sleeves on our slabbing-mill rolls are removable and have not been trouble-free. They are fairly readily interchangeable, but demand a standard of fitting which is hardly practicable under average working conditions. Many have worked loose, and they are a source of slight but ever-present concern.

I have said that the taper sleeves fitted to our strip-mill back-up-roll necks are entirely satisfactory; perhaps I should qualify this by adding "as bearing surfaces." Many of these back-up rolls have failed through the neck after about 20,000,000 reversals of stress under rolling load, and always under the taper sleeve. If the neck were solid the available cross-section capable of supporting load would be increased by nearly 50%. One is inclined to ask, therefore, why solid parallel necks should not be substituted for shrunk or fitted taper sleeves. In one case they would eliminate sleeve-fitting trouble, and in both cases neck strength would be appreciably increased and roll construction simplified.

Cast roll material in chilled iron or steel is not, at first sight, capable of the degree of surface finish desirable in a film-lubricated white-metalled bearing. Forged steel should be better. Though none are necessarily as perfect as a special sleeve of appropriate material, provided that proper attention is paid to neck-surface density, hardness, and finish, any normal roll material should be satisfactory. Recent experiments at Shotton tend to confirm this; possibly rolling-mill manufacturers present have similar experience.

Mr. W. S. Robertson (Messrs. W. H. A. Robertson & Co., Ltd.): The comments of the last speaker concerning the running of rolls in white-metal film-lubrication bearings without any sleeve are perfectly correct. My own company has made many hundred mills of that design, and we have never had any trouble from difficulties with the roll necks. We have made mills with all the designs of bearings which have been described this afternoon, and, as has already been stated,

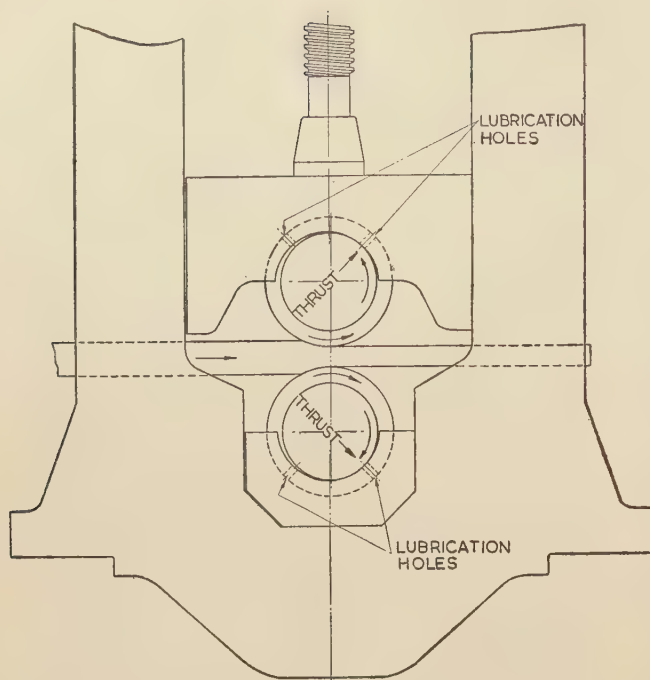


FIG. A—Diagram showing the difficulty of introducing lubricant into the bearing, because of the direction of thrust of the roll neck owing to the passage of the bar through the rolls. The clearances shown are exaggerated

each particular problem requires its own solution and what is correct for one is not correct for others. The virtue of the oil-film-lubrication bearing has been emphasized already, *viz.*, the larger neck diameter. The difficulty is the oil seals. The virtues of the roller bearing are, of course, that there are no difficulties with oil seals. The difficulty is the smaller neck diameter. I would also say that, in supplying these mills, success is very often achieved with one company where it is not achieved with other companies, and the success of one type of bearing or another depends largely on the way in which the bearings themselves are maintained.

Mr. G. R. Walshaw : I spoke for my Company on the oil-film bearings, and, as the question of roll breakage has been raised, I should like to say another word about them. We have broken backing rolls without any damage whatever to the Morgoil bearings. We have also broken a roll neck inside the sleeve, and this was revealed only by the behaviour of the plates, which ran into the necks instead of coming out straight. Investigation showed that the neck was clean broken in two, but the Morgoil bearing was running and giving no trouble at all. At no time have the bearing surfaces given any trouble, and repairs

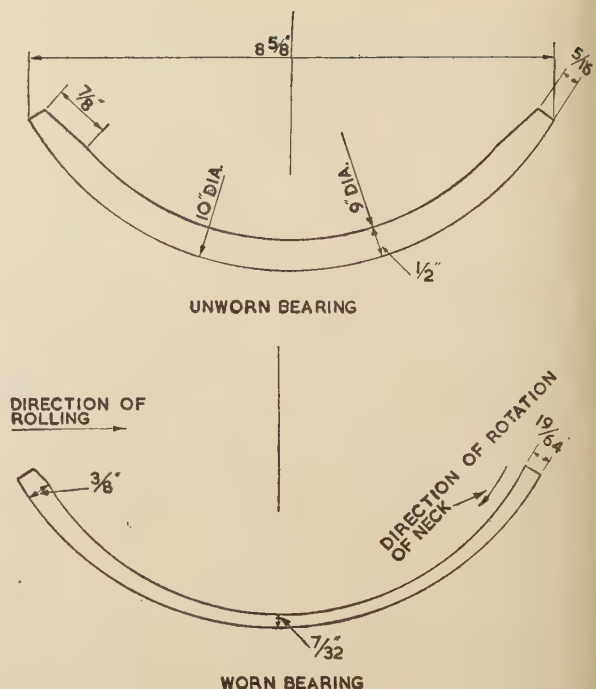


FIG. B—Effect of wear on a fabric bearing in a 15-in. three-high non-reversing mill (bottom roll)

have been confined chiefly to the oil- and water-seal rings.

There are, however, many existing mills which, because of the design of the housings or because there are very large numbers of existing rolls, cannot be adapted for oil-film lubrication, *e.g.*, at the Frodingham 32-in. section mills there exists over 300 pairs of rolls which do not lend themselves to the type of bearing which has proved successful in the plate mill. In these mills we have made one change enabling us to use white metal in place of the old phosphor-bronze bearings and thus secured much better life and working conditions for the roll bearings and necks.

The necks varied in diameter from $17\frac{1}{2}$ in. to 18 in., so a large number of hard cast-steel sleeves were bought, and, as rolls came in to be dressed, the necks were trued up and the sleeves shrunk on and then turned up to a standard size of $19\frac{1}{2}$ in. dia. It was found that $\frac{3}{4}$ in. was the thinnest sleeve which could be put on without slipping during use, and even at $\frac{3}{4}$ in. one or two have become loose.

The increase in diameter of the roll necks has considerably improved the life of the bearings, which are lubricated by grease from a continuous automatic pumping system, and has also resulted in much improved neck surfaces.

There is one fundamental difference between the bearings on a four-high mill as described in

ny paper and the bearings on the two-high mills just mentioned.

In a two-high mill, when a bar or plate enters the rolls and is passing through, the rolls are pushed hard over to the outgoing side of the mill. The roll neck, therefore, is pressed hard against the surface of the bearing at the side into which the journal of the roll neck is entering, and all the clearance between the journal and the bearing is on the side on which the journal is emerging from the bearing. Reference to Fig. A will make this clear. The direction of greatest wear is shown by the sketch (Fig. B) of a worn bearing from the bottom roll of a three-high mill using fabric bearings.

In an ordinary bearing, such as a locomotive axle-box, the journal is entering the bearing where the clearance is greatest, and thus carries the oil with it in a nice wedge into the region of maximum pressure, but in a two-high mill no grease or oil wedge can be formed, and the lubricant has to be forced in at the point of highest pressure by grease pumps working at 1000–3000 lb./sq. in.

On the other hand, on the clearance side of the roll-neck bearing, the emerging rotating neck, assisted by gravity, actually draws the grease out of the grease pocket and deposits it on the carrier chock under the top neck in the case of the top roll. On reversal of the mill, the clearance side becomes the pressure side, owing to the thrust of the bar entering the rolls, and no grease is fed to the bearing until the grease pocket is replenished with grease by the pump and pressure established again.

In the four-high mill, although the thrust is in the same direction, the rotation of the backing-roll necks or sleeves is opposite-hand, and oil is drawn into the clearance space by the journal itself.

I would like to add that I appreciate very much the information given to us this afternoon, especially that on white-metal and fabric bearings as applied to non-specialized mills. The results are very good indeed and show that there is still a great future for these two types of bearings on mills which have to carry on with existing rolls and existing stands.

The Chairman: One speaker said that all Morgoil bearings were running with roller-bearing thrusts, but that is not so. The widest trip mill in the world, 98 in., runs on Morgoil bearings with standard Morgoil disc thrusts. They did have trouble at the start, but they quickly discovered what it was and put it right, and the mill now runs trouble-free on disc thrusts.

Mr. W. P. Snedden: I did not refer to the

Morgoil bearing but to the Mesta oil-sleeve bearing having taper roller thrust units.

On the motion of the Chairman a vote of thanks was accorded to the four speakers who opened the discussion, and the meeting then terminated.

Written Contributions

Mr. O. C. Higgins (Tanway, Ltd.): The authors of the five papers so ably presented at this meeting are indeed to be congratulated. Seldom has one such gathering been productive of so much interesting information and useful fact.

In view of the wide scope of Mr. Knight's subject matter, he was of necessity only able to deal with each section in a general rather than in a detailed manner. Nevertheless, that did not make his remarks any the less interesting. The writer was particularly impressed with the attention paid to lubrication generally in the U.S.A. and the tendency in that country to duplicate equipment in order to insure against interruptions of production. In view of the capital value of the plant and the necessarily high overheads, this is undoubtedly a wise policy. It was, I believe, Mr. Craig who mentioned that his concern regards lubrication arrangements as being one of the earliest matters to be decided when a job is first laid out in the drawing office. Evidently it is not only the American engineers who realize the extreme importance of lubrication in relation to successful plant operation.

Mr. Borland showed conclusively the benefits to be derived from adopting centralized grease lubrication in combination with white-metal bearings, whilst Mr. Walshaw proved that with flood-lubricated, totally enclosed bearings a still better performance is obtained.

With centralized grease systems and open bearings, roll changing is a simple matter and, further, the lubrication equipment and bearings are both relatively inexpensive. But, however liberally grease may be applied, lubrication remains more or less of the boundary type, with the result that friction and wear are necessarily greater than in the case of full fluid-film lubrication. Further, a grease-lubricated mill is usually a dirty mill.

Totally enclosed flood-lubricated bearings reduce friction and wear to a minimum, are clean, and they give excellent service. On the other hand the lubrication equipment is considerably more costly, roll changing becomes a more complicated matter, and the capital cost involved is much higher. Nevertheless, on the larger mills,

particularly when roll changes are infrequent, the use of flood-lubricated bearings can easily be justified. The back-up rolls on a continuous-strip mill are, for example, obviously suitable for that type of bearing.

Mr. Knight has an unusually wide experience in lubrication matters by no means confined to grease, and Mr. Borland has evidently given the subject particularly careful attention. The writer would like to ask both these gentlemen, in view of the following facts, why there should not be an intermediate stage between centralized grease and full-flood lubrication for use on roll-neck bearings which combines many of the advantages of both systems.

Mr. Knight and Mr. Borland may be interested to know of a method which is growing in favour and which is applicable to the open type of chock. This consists of the injection of a controlled continuous small stream of suitable oil into the entering side of each bearing. The system is comparable to the centralized grease system as regards simplicity—only rather more so—but with certain important differences: (a) The lubricant stream is continuous, thus avoiding dry periods between pump strokes or injection periods, and (b) if proper attention is paid to the fit of the bearings and the condition of the necks, lubrication approaches very closely indeed to the fluid-film type upon which the excellent performance of the flood-lubricated bearing depends.

In view of the large quantity of oil circulated through the latter type of bearing, the suggestion that fluid-film conditions can be maintained with the injection of only a small stream may sound extravagant. However, since the thickness of the oil film at the line of maximum load is exceedingly small—Dr. Underwood in "Roll Neck Bearings" mentions $1\text{--}5$ and says it may even be as small as $1\text{--}4$ —and since the mean oil velocity past that line must be a good deal less than the peripheral velocity of the neck, simple calculation will show that the quantity of lubricant actually entering and travelling round between neck and bearing surface is indeed very small.

In the long run it is results that count. The mill floor is no easy testing ground. Running experience with the continuous oiling system above-mentioned has shown that where it has replaced the centralized grease system, the improvement in bearing performance has been remarkable. On one 18-in. three-high hot-section mill converted from centralized grease, the reduction in chock failures and in power required to drive exceeded all expectations. On a new 14-in. four-stand, two-high hot-bar mill recently put down in the Sheffield area the owners report

a lubricant consumption of 0.0343 gal. per ton of steel, which works out at 1.76d. per ton. All the white-metal linings remain perfectly cool, and wear is proving negligible. It is interesting to note with regard to this mill that the calculated quantity of make-up oil necessary to maintain fluid-film conditions for all the mill bearings is something not exceeding, and probably less than, 0.075 gal./hr. The actual recorded consumption amounts to 0.0625 gal./hr. It would therefore appear that theory is tying up pretty well with practice and that fluid-film conditions, or something closely approximating thereto, are being maintained. As regards the power required to drive this mill the owners say that, compared with the older form of grease lubrication, of which they still have a number of examples in their mill, they estimate that the reduction amounts to about 40%. This represents a considerable saving in capital cost.

The writer believes that the above facts do go to prove that there is available a system intermediate between centralized grease, boundary lubrication so excellently described by Mr. Borland, and full-flood lubrication—the subject of Mr. Walshaw's remarks—and, further, that this method combines the simplicity and economy of the former system whilst giving to a large extent the benefits of the latter system. The writer would appreciate any comments that Mr. Knight, Mr. Borland, and Mr. Walshaw care to make on the subject.

Dr. H. Ford (British Iron and Steel Research Association): The four speakers described roll-neck-bearing systems which have been carefully chosen for the conditions in each particular mill and which have been properly installed and operated. It is also clear that in all cases the bearings have received careful maintenance and that proper records have been kept of the performance of each set of bearings installed. These are the requirements for the successful performance of any bearing, and it is significant that very good results have been obtained in all four applications.

The British Iron and Steel Research Association has been carrying out, under the auspices of its Rolling Committee, a works investigation of the performance and life of various types of roll-neck bearings. This has been preceded by a thorough examination of the literature on the subject by Dr. L. R. Underwood for the Rolling-Mill Committee of what was then the British Iron and Steel Industrial Research Council. A comprehensive report of this literature survey was published by the British Iron and Steel Industrial Research Council in 1943 under the title "Roll

Neck Bearings, Part 1—Design, Construction and Operation.” It is intended that Part II of this work should include all the operating experiences and information collected during the present works studies.

A works survey of this type naturally takes a long time, since, to obtain representative and reliable information about a given type of bearing in a given type of mill, details must be collected over at least six months and in many cases a year or more. However, after nearly two years, we have obtained some general impressions, and these may be of interest.

What constitutes a good bearing? There are a large number of factors which should be taken into account, but the main considerations involved are:

- (a) Life before scrapping.
- (b) Capital costs and replacement costs.
- (c) Running and maintenance costs.
- (d) Replacement time, and convenience during roll changing.
- (e) Power consumption.

These factors contribute to the cost per ton of steel rolled, and over long periods of operation this is the main consideration.

In many plants in the industry the mills are not of such recent construction as those referred to by the four speakers, and it is necessary to extract the greatest economy from these existing mills. In actual fact we have found that some of the older plants have very efficient roll-neck bearings which are run at low cost and with little trouble. These are often of the simplest type, with negligible installation charge and maintenance costs. In many cases excellent results are obtained, while other apparently similar installations give poor life and high power losses.

Our results so far have led us to conclude that a given roll-neck-bearing assembly will show success or failure in proportion to the attention paid to the following points, which are placed in order of importance:

- (1) Regular examination and maintenance by a responsible individual.
- (2) In hot mills, adequate arrangements for excluding scale from the bearings.
- (3) Proper lubrication, properly applied.
- (4) Proper alignment of the mill.
- (5) Reasonably good condition of the roll necks.

Our experience has been that where unsatisfactory results as to life and costs are found they can usually be traced to one or more of these five factors.

We have found very successful and efficient installations of the apparently simplest type, frequently made in the works and requiring no costly chock assemblies; these bearings can be rapidly fitted and changed over and do not interfere with the roll change. The main reasons for success of what appear to be quite primitive arrangements are, as far as can be ascertained, that due regard has been given to the foregoing five factors. In all cases we have found that adequate scale guards have been fitted to the successful mills, and the lubricant has been applied at the right point and in the right amount.

The four systems which the speakers have described undoubtedly represent the latest practice and are clearly very successful, but I am convinced that excellent results can be obtained in the many hundreds of hot mills throughout the industry, using their existing roll-neck-bearings arrangements if regular and reasonable attention is given to them and the design is sound in the particulars listed above.

It should, however, be understood that these remarks do not apply to the roll-neck bearings of cold mills, where the bearing loads are much higher than in hot-rolling mills. In cold mills really satisfactory results can only be obtained from specially designed bearing assemblies, and choice is more or less confined to the fluid-film or the roller-type bearings.

Turning now to the individual papers, I should like to ask Mr. Jones why he considers that the bearings on the roughing end of the rolls are more heavily loaded than those on the finishing end in his mill. I do not now remember the disposition of the various passes in the rolls, but I think he remarked that the two bearings which failed most rapidly were the bottom-roughing and the top-finishing; he thought that the latter was an unexpected result. Without knowing the roll-separating force it is impossible to say which of the two sides of the mill is the more heavily loaded, and I wonder whether Mr. Jones has been able to make any assessment of roll force on the two sides of the mill.

With regard to white-metal bearings, it would appear from those installations which we have seen or have investigated that care must be taken in their use and that further research into the composition of the white metals employed could be profitably undertaken. As Mr. Borland has shown, white-metal bearings will give very good results in certain instances, but this is not always the case; we know of one example which gives an outstanding performance, but it would seem that an even greater life could be obtained with further development.

To achieve the best results for white-metal bearings the following points should be closely observed :

- (i) Adequate and suitably designed grease-grooves.
- (ii) Sufficient "under-the-surface" reinforcement to check any flow of the metal.
- (iii) Research and experiment into the best compositions of white metal.
- (iv) Efficient scale guards.
- (v) Good roll-neck finish.
- (vi) Sufficient bearing coolant.
- (vii) Correct roll alignment, with sufficient clearance for longitudinal expansion. Detachable phosphor-bronze collars should be fitted if the thrust problem cannot be solved.

In the future it is possible that white-metal bearings may be modified for use with oil as lubricant instead of grease. It is said that thinner layers of white metal can be used and that there is a reduction in lubricant costs. These developments are as yet in their infancy, but they certainly look promising.

In Mr. Pearson's very interesting table of operating data for the roller bearings on the Ebbw Vale five-stand cold mill, I was surprised to find that the first stand gave such a high value of roll-separating force (2×10^6 lb.). (See Table A.) This led us to do a few calculations to see whether the experiments we have carried out on a small cold-rolling mill could be used to check these figures. We can measure roll force and torque accurately, and have developed methods for making rapid calculations of roll force and energy consumption which are sufficiently accurate for practical purposes.

As we had no figures for gear-box and motor losses, we had to make some assumptions.* The losses considered were :

- (a) Electrical and mechanical losses in the motors.
- (b) Gear-box and pinion losses.
- (c) Roll-neck-bearing losses.

(a) Motor Losses

It will be seen that the input to the motors varied from 600 to 1680 h.p. Motor efficiency would certainly not be constant over this range,

* I am grateful to Mr. C. N. Kington, M.B.E. (British Iron and Steel Research Association), for help in carrying out the calculations.

and, not having motor-efficiency curves, we made the assumption that the efficiency was 75% at 400 h.p. and 95% at 1700 h.p., with linear variation in between. This is, of course, not strictly correct, as efficiency curves are not straight lines, but it does allow in some measure for the variation of efficiency with increasing load.

(b) Gear-Box and Pinion Losses

The only reliable statement we could get for drives transmitting powers of the order under consideration gave average efficiencies as 95%.

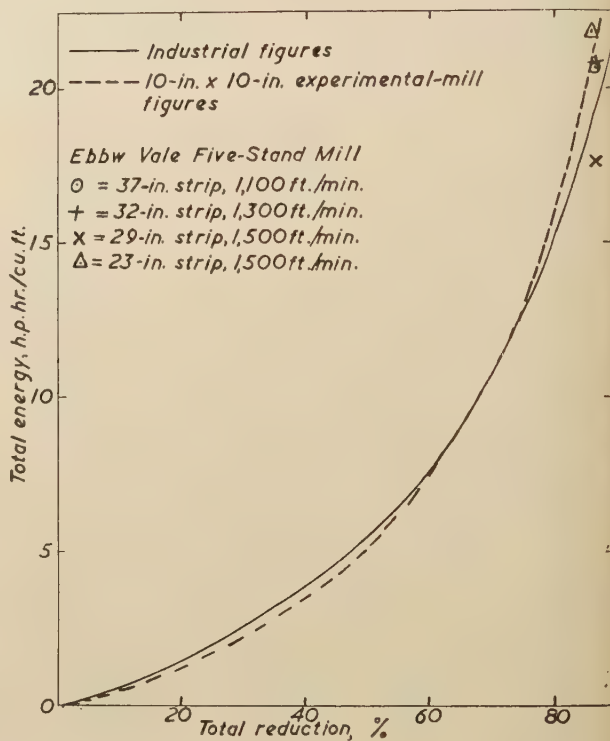


FIG. C—Energy-consumption data for low-carbon rimming-steel strip from various mills

However, since tests made on our experimental equipment showed that part of this is made up of churning losses and other speed-dependent losses, we assumed the following :

Fixed loss	...	2½%
Speed-dependent loss	...	Zero at minimum speed and 5% at maximum speed, making a variation of from 2½ to 7½% altogether.

(c) Roll-Neck-Bearing Losses

For the calculation of roll-neck-bearing losses we used the formula :

$$\text{Frictional bearing loss} = \frac{2\pi N}{33,000} \times \frac{\mu P d}{2}$$

where N = revolutions per minute,

P = total roll force, pounds.

μ = coefficient of friction (assumed 0.0025 for roller bearings),

d = bearing diameter, feet (assumed 0.70 of roll diameter).

These efficiency figures give the results shown in Table B.

In using the formula for roll-neck-bearing friction, the values of roll force, P , were calculated, using a yield-stress curve obtained for a 0.07% carbon rimming steel. Consideration of the tension conditions in the strip revealed that the effect of the tension on roll-force values at the five stands was not sufficient to cause an appreciable alteration to the friction losses at the roll-

neck bearings. This is because the roll-neck-bearing losses are directly proportional to the total roll force which, in this case, is only slightly affected by the tension existing. It is not, in fact, necessary to know the value of P very accurately at this stage.

In Fig. C will be found a curve connecting total energy consumption in horse-power-hours per cubic foot with the total percentage reduction, representing (by the full line) the mean line through a large number of experimental results obtained on wide-strip mills and other cold-reduction mills, with rolls varying in diameter from 16½ in. to 20 in.* for low-carbon rimming steels. Also included is the mean line through a large number of separate tests made on a 10 in.

* See "The Modern Strip Mill." Association of Iron and Steel Engineers, 1941; see also Feinberg, *Stal*, 1943, vol. 3-4 p. 27.

TABLE A—Readings Taken from Item 2, Table III

Roll diameter, 20 in.; initial strip, 32 in. × 0.083 in.; finished-strip gauge, 0.011 in.

Stand No.	Initial thickness, in.	Final thickness, in.	Pass reduction, %	Total reduction, %	Speed ft./min.	Power, h.p.	Roll force, lb.
F1	0.083	0.060	27.7	27.7	238	600	2 × 10 ⁶
F2	0.060	0.040	33.3	51.8	355	940	1.2 × 10 ⁶
F3	0.040	0.026	34.8	68.7	545	1000	1.2 × 10 ⁶
F4	0.026	0.017	33.9	79.5	825	1000	1.4 × 10 ⁶
F5	0.017	0.011	34.2	86.5	1300	1680	1.5 × 10 ⁶
Coiler	0.011				1300	230*	

* Figures for the coiler power were not given, and it has been assumed that the coiler runs at full output.

TABLE B—Power and Energy Consumption for Five-Stand Mill, Ebbw Vale

	Stand F1	Stand F2	Stand F3	Stand F4	Stand F5	Coiler
Power usefully used, h.p....	440	724	720	630	1135	200*
Energy, h.p.hr./cu. ft. ...	2.35	3.97	3.95	3.37	6.08	1.05
Total energy, h.p.hr./cu. ft.	2.35	6.32	14.27	13.64	19.72	20.77

* Maximum

TABLE C—Estimated and Measured Roll Force in Five-Stand Mill

Roll Force	Stand F1	Stand F2	Stand F3	Stand F4	Stand F5
(1) Measured (lb.) ...	2 × 10 ⁶	1.2 × 10 ⁶	1.2 × 10 ⁶	1.4 × 10 ⁶	1.5 × 10 ⁶
(2) Estimated (lb.) ...	0.76 × 13 ⁶	1.26 × 10 ⁶	1.38 × 10 ⁶	1.61 × 10 ⁶	2.22 × 10 ⁶
(3) Percentage difference = 100 × $\frac{(2) - (1)}{(2)}$	− 162%	+ 4.6%	+ 13.0%	+ 13.0%	+ 32.2%

× 10 in. experimental mill* with the 0.07% carbon rimming steel mentioned above. All the results have been corrected for mechanical losses in the rolling mill, the figures representing the energy used in deforming the material. The mean line is shown dotted. The figures given by Mr. Pearson, after correction as above, are added and are denoted by the symbols shown. It will be seen that the agreement is good, bearing in mind the possible errors in making the readings and in assessing the losses. The results for all four tests on the Ebbw Vale plant are given, calculated as described above for the second test.

We then attempted more accurate calculations of roll force. A rough assessment of the strip tension between stands indicated that the values of roll force for the first three stands are unlikely to be greatly affected by the tensions existing, and we consider an assumption of no tension at these stands is justified. Detailed calculations on the fourth- and fifth-stand conditions indicate that the tensions at these stands were of the following order :

Fifth stand :
 Front ... 6-7 tons/sq. in.
 Back ... 7-8 tons/sq. in..

Fourth stand :
 Front ... 7-8 tons/sq. in.
 Back ... Zero (assumed)

Owing, however, to the heavy total reduction reached at these stages (fifth = 86.5%, fourth = 79.5%) and the consequently low ratios of strip tension to yield stress, we did not consider it was worth while, without a more reliable assessment of inter-stand tension, to insert values of strip tension in our calculations for roll force.

Table C therefore gives a comparison of our calculated values of roll force, ignoring tension effects, with Mr. Pearson's measured values. The effect of what tension there is at stands *F4* and *F5* would be to lower our figures slightly and it will be seen that they are higher than Mr. Pearson's, although we do not consider the strip tensions would lower the results to the extent required.

The agreement is quite good, except for stand *F1*, where the measured value appears to be much higher than the calculated value. The energy consumption in this stand is quite low (2.35 h.p.hr./cu. ft.) and the power on the stand is small compared with the other stands; the material would be fairly soft and there is no reason to suppose that the calculated value is particularly low, as the yield-stress curve we used was on the

high side for the type and condition of the material.

I should be glad to have any comments from Mr. Pearson on (a) how the roll force was measured, (b) whether any particular circumstances led to the high value for stand *F1*, and (c) whether bearings on this stand show the effect of a high bearing load.

All four speakers should be complimented on the interesting information and statistics they have supplied, and it is to be hoped that we shall have further opportunities for discussion of other factors in the design and operation of rolling mills.

Author's Reply

Dr. Ford has obviously made a very close study of the subject of all factors concerned in steel rolling, and the results he has obtained will undoubtedly be of great assistance to mill designers, operators, and maintenance staffs generally; his contribution is of the very high standard we expect from Dr. Ford. As to the queries he has raised, I would answer as follows :

(a) The roll force was measured by direct reading from the normal pressure-meter equipment on our cold-reduction mills, but it should be understood that as there was so little time given for the preparation of the paper it was quite impossible to make a complete set of experimental tests under the very close control and supervision that would be desirable; figures taken from ordinary production conditions were therefore used, merely as an illustration of a certain set of conditions, which, as Dr. Ford appreciates, can vary very considerably even during the period of one hour's rolling.

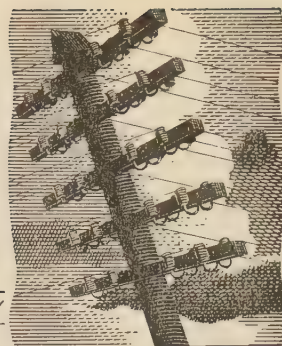
(b) With regard to Dr. Ford's second question, namely, whether any particular circumstances led to the high value for stand *F1*, high values for any individual stand can vary quite considerably from coil to coil, depending upon several related conditions, such as (i) any check in roll-cooling water, (ii) blocking of the lubrication jets, causing temporary changes in the surface conditions as between roll and strip, (iii) roll form, (iv) screw setting, (v) speed, and, last but not least, (vi) the physical condition of the strip.

(c) We have not found any indication in actual practice that the bearings on stand *F1* show any effect of high bearing load, but owing to the fact (as stated in the paper) that we change these bearings around throughout our mills, it is difficult definitely to allocate certain features which show up in the bearings to any particular stand.

* See H. Ford, *Journal of the West of Scotland Iron and Steel Institute*, 1944-45, vol. 52, Part 4, p. 59.

N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY



THE IRON AND STEEL INSTITUTE

Annual General Meeting, 1947

The **Annual General Meeting** of the Institute will be held on Wednesday, Thursday and Friday, 14th, 15th and 16th May, 1947.

The **Technical Discussions** on Wednesday, 14th May will be held at the offices of the Institute at 4, Grosvenor Gardens, London, S.W.1; those on 15th and 16th May will be held in the Lecture Theatre of the Institution of Civil Engineers, Great George Street, London, S.W.1.

There will be a **Dinner for Members** and their guests at the Connaught Rooms, Great Queen Street, London, W.C.2, on Thursday, 15th May, at 7.15 P.M.

The **Second Hatfield Memorial Lecture** will, by agreement with Sheffield University, be delivered by Dr. C. SYKES, F.R.S., (Brown-Firth Research Laboratories). The lecture, entitled "*Steels for Use at Elevated Temperatures*," will take place at 8.30 P.M. on 14th May, 1947, in the Hall of the Institution of Civil Engineers.

A circular (No. C.694), giving full details of the programme, is being sent to all Members.

Symposium on Powder Metallurgy

A Symposium on Powder Metallurgy will be held in the Lecture Theatre of the Institution of Civil Engineers, Great George Street, S.W.1, on the afternoon of Wednesday, 18th June, and all day on Thursday, 19th June. An exhibition of powder-metallurgy products will be on view at the meeting. A Buffet Luncheon will be held in the Library of the Central Hall, Westminster, S.W.1, on Thursday, 19th June.

The Symposium is being held to discuss a number of papers on some ferrous and non-ferrous aspects of Powder Metallurgy. A circular notice about the meeting will shortly be issued to all members of the Institute and of the Institute of Metals.

Invitations have been issued to the Institution of Mechanical Engineers, the Institution of

Electrical Engineers, the Institute of Production Engineers, the Institution of Automobile Engineers and the Society of Chemical Industry, stating that members of these Societies who wish to attend the Symposium will be very welcome.

The papers to be discussed at the Symposium will be published as Special Report No. 38 in the Special Report series of the Iron and Steel Institute. Copies of this Special Report will be on sale, shortly before the meeting, at a published price of 16s. per copy, with a specially reduced price of 10s. per copy for members of the Iron and Steel Institute and the Institute of Metals. Orders for Special Report No. 38, with the necessary remittance, should be sent to the Secretary, the Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1, as soon as possible.

Details of the times of the sessions at the meetings and of the subjects to be discussed at each session will be announced later.

Papers at Meetings

The Council regret that it is not possible, at present, to supply reprints of papers selected for discussion at meetings. Those attending are therefore requested to bring with them copies of the monthly *Journal* in which the papers are printed.

Supplies of paper are still strictly limited and it is only by the exercise of careful economy that the present size of the *Journal* can be maintained. When restrictions are removed it is hoped to supply reprints and thus to relieve Members of the inconvenience of bringing the *Journals* with them.

The Ablett Prize

Captain C. A. Ablett, O.B.E., B.Sc., M.Inst.C.E., has agreed to renew his prize of £50 and has accepted suggestions made by the Council of the Iron and Steel Institute for changing the conditions governing the award.

In future the prize will be given annually, on the recommendation of the Engineering Committee, to the author of a paper on a subject connected with engineering in iron or steel works. The Committee, in making their recommendation, will take into consideration all papers on suitable subjects published in the *Journal*, including those which have been presented to the Iron and Steel Engineers Group, and will take account of the age and position of the authors so as to give due attention to the donor's primary intention of encouraging younger engineers in iron and steel works. Engineers are invited to submit papers to the Secretary.

The Ablett Prize was first made available in 1938, and was awarded in 1939 to H. Escher, (Australia) for his paper on "*Ten Years' Development in Steam Engineering at the Port Kembla Steelworks, N.S.W., Australia.*" The prize was not awarded during the war.

Sir Robert Hadfield Medal

The Council of the Iron and Steel Institute announce that they have decided to found a Sir Robert Hadfield Medal, using for this purpose a legacy of £250 left to the Institute by the late Sir Robert Hadfield, Bt., F.R.S., Past President and Bessemer Gold Medallist.

The Medal will be awarded annually to mark the Council's appreciation of meritorious service in improving the technique of the production of iron and steel, or in developing the science of metallurgy, and as an encouragement for further work. In making the award the Council will interpret these terms of reference widely so as to include fuel economy, refractories and engineering, as well as ferrous metallurgy and other aspects of iron and steel works' practice.

It will be a condition of the award that the recipient is a Member (of any class) of the Iron and Steel Institute and that he has not previously received the Bessemer Gold Medal. It will be open to the Council to award the Medal jointly to two recipients in one year.

The Medal will be struck in stainless or heat-resisting steel. A design has not yet been prepared.

The Council has decided to award the first Sir Robert Hadfield Medal to John Hugh Chesters, D.Sc.(Tech.), Ph.D., (The United Steel Companies, Ltd.), in recognition of his work on refractories for use in the iron and steel industries and for his share, as co-author, in preparing Special Report No. 37 (1946) on "*The Influence of Port Design on Open-Hearth Furnace Flames.*" The award will be made at the Annual General Meeting on 15th May, 1947.

Staff Biography No. 4

Mr. ANTHONY POST was born in London in 1912. He was educated at Winchester College, and at Magdalen College, Oxford, where he read Physics.



On leaving the University he joined the staff of a firm in the London Stock Exchange. In 1937 he became a member of the Stock Exchange and operated in the American Security market. In March 1937, he obtained a commission in an anti-aircraft

unit of the Territorial Army and was embodied for war service in August 1939.

During the war he served in anti-aircraft units and on the staff in England until 1943, and then in the Middle East. In 1944 he qualified at the Military Staff College at Haifa and was posted to Aden, where he became principal Military Staff Officer on the staff of the Air Officer Commanding in Aden, with the rank of Lieutenant-Colonel.

Mr. Post joined the Institute staff in 1946, after spending some time touring various steel works, in company with members of the staff of the British Iron and Steel Research Association. He acts as Secretary to the Iron and Steel Engineers Group, and has taken an active part in arranging the three meetings, held in London by the Group, since its inception in July 1946.

In September 1946 he went to Düsseldorf with Dr. M. A. Vernon, the Information Officer, to study the Information Department of the Verein Deutscher Eisenhüttenleute, with the object of embodying some aspects of the German system into the new and enlarged Information Department of the Institute. He will be responsible for much of the detailed organization of the Special Summer Meeting which will be held in Zurich this year.

BINDING CASES Monthly Journal

With the publication of the April issue of the *Journal*, volume 155 is now complete. Normally, binding cases would now be issued for this volume, to contain the first four parts of the monthly *Journal* in the new series.

As some Members and Subscribers have intimated that they do not wish to receive binding cases, and in view of the serious shortage of materials and labour at the present time, it has been decided to send binding cases only on request. An application form for the cases (which are free of charge) appears on page 39 of the Advertisement Section in this issue.

NEWS OF MEMBERS

Recent Appointments

Mr. J. MOWAT has been appointed Chief Metallurgist, and Head of Research, of Messrs. William Beardmore & Co., Ltd.

Mr. A. H. MILNES has taken up an appointment, as Chief Metallurgical Engineer, with The Steel Improvement and Forge Co., Cleveland, Ohio, U.S.A.

Mr. F. Cousans has left Messrs. Catton & Co., Ltd., to join the staff of Messrs. Hadfields, Ltd., Sheffield.

Mr. R. S. POISTER, former Manager of the Chicago District, Youngstown Sheet and Tube Corporation, has been made Vice-president of the Crucible Steel Company of America, Pittsburgh, Pa., U.S.A.

Mr. S. SMITH has been appointed Managing Director of the Wellman Smith Owen Engineering Corporation, Ltd.

Mr. A. H. CARRINGTON has been appointed Manager of the Welding Department of Messrs. G. D. Peters & Co., Ltd.

Mr. D. E. DARGENT is leaving the Providence Steel Plant, Hautmont, France, to join the Fabrique de fer de Charleroi, Belgium.

Mr. LOUIS RIPLEY, O.B.E., has joined the Board of Messrs. Blackett, Hutton & Co., Ltd., Yorks.

Mr. F. PICKWORTH has been appointed Chairman of Messrs. Taylor Bros., & Co., Ltd.

Elections

Dr. E. OROWAN has been elected a Fellow of the Royal Society.

Mr. D. CLARK has been elected President of the Australian Institute of Metals for 1947.

Mr. T. H. SUMMERSON has been elected to the Grand Council of the Federation of British Industries for 1947-1950.

Awards

The President and Members of Council offer their congratulations to:

Dr. J. E. GARSIDE, who has been awarded the Constantine Medal of the Manchester Association of Engineers.

Mr. K. J. IRVINE, who has been awarded a Nuffield Foundation Travelling Scholarship.

Obituary

The Council regret to record the death of:
Mr. R. B. HARLAND WALSHAW.

IRON AND STEEL ENGINEERS GROUP

The **Fourth Meeting** of the Iron and Steel Engineers Group will be held at 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 11th June, 1947.

The meeting will consist of a morning session devoted to a discussion on "*Steam Generation and Utilization in Iron and Steel Works*," and an afternoon session devoted to a discussion on "*The Application of Gas Turbines to Iron and Steel Works Practice*."

A Buffet Luncheon will be held between the two sessions.

Papers for discussion at the Meeting will be published in the *May Journal*. A circular notice about the meeting will shortly be sent to all Members of the Group.

THE BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Staff Appointments

Mr. R. H. MYERS has been appointed Head of the Steelmaking Division.

Dr. HUGH FORD left the Association in February, and Mr. HESSENBERG is to be appointed the new Head of the Mechanical Working Division, in May, 1947.

Mr. E. H. DIXON has left the Materials Research Laboratories of Philips Lamps Ltd., to join the Steelmaking Division of the Association.

Mr. ROGERS has been transferred from the Physics Department to the Steelmaking Division, where he will be working on the instrumentation of Open-Hearth Furnaces.

INSTITUTION OF METALLURGISTS

Refresher Courses—Preliminary Notice

The Institution will be holding a Refresher Course at the L.M.S. School of Transport, Derby, on 5th, 6th and 7th September, 1947, commencing with the first lecture at 8.0 p.m. on Friday, 5th, and dispersing after luncheon on Sunday, 7th September.

The subject of the course will be: "*Transformations in Solid Metals and Alloys*."

The Course will be residential and good accommodation is available at the L.M.S. Transport School. The total charge will be between £3 and £4.

Final details of the programme of the Course, the lectures, cost, and particulars of registration will be published shortly.

CONTRIBUTORS TO THE JOURNAL

John Glen, B.Sc., A.R.T.C.—Metallurgist at Messrs. Colvilles, Ltd., Motherwell. He received his metallurgical training at the Royal Technical College, Glasgow, and gained a Hart Scholarship in 1931. Mr. Glen graduated in 1934, with Honours in Metallurgy, Physical and Organic Chemistry. He was awarded Associateship of the College, and also received an 1851 Exhibition Scholarship. Joining the staff of Messrs. Colvilles Ltd., in 1934, he dealt with production research problems. In 1938 he was given charge of the High Temperature Testing Laboratory, and during the war he worked on problems relating to armour plate.

Mr. Glen is an Associate of the Institution of Metallurgists. He has presented a number of papers to the Iron and Steel Institute and to the West of Scotland Iron and Steel Institute.

Robert Fowler—Blast-Furnace Manager with Messrs. Richard Thomas & Co., Ltd. He received his education at Middlesbrough High School and Constantine Technical College. His early training in blast-furnace practice was gained with Messrs. Bolckow Vaughan & Co., Ltd. In 1921 Mr. Fowler went to Kulti, India, where he was Assistant in the Blast-Furnace Department of the Bengal Iron Company Ltd., until 1926. He was appointed Superintendent of Blast-Furnaces at the Hirepur Works of the Indian Iron and Steel Company in 1926, and he returned to Britain in 1935, to join the staff of Messrs. H. A. Brassert & Company. After being in charge of the reconstruction of the blast-furnace plant at the Ebbw Vale Works of Messrs. Richard Thomas & Co., Ltd., he joined this company in 1936. Mr. Fowler has been a Member of the Institute since 1937.

John Warlow Houghton, Assoc.Met.—Blast-Furnace Manager at the Park Gate Iron and Steel Co., Ltd. He received his technical education at the University of Sheffield and was awarded an

Associateship in Metallurgy in 1933. He joined the Metallurgical Department of the Park Gate Iron and Steel Co., Ltd., in 1933, was appointed Assistant Blast-Furnace Manager in 1937, and took up his present appointment, as Manager, in 1940.

Mr. Houghton was elected a Member of the Iron and Steel Institute in 1937, and was accepted as an Associate of the Institution of Metallurgists this year.

E. J. Vaughan, M.Sc.—Superintending Scientist at the Naval Ordnance Inspection Department, Bragg Laboratory, Sheffield. Mr. Vaughan graduated from London University, having carried out research in physical chemistry at the Royal College of Science. He entered the service of the War Office in 1925, as Junior Assistant Chemist and transferred to Admiralty Service in 1927, serving for nine years at Portsmouth. He joined the Bragg Laboratory in 1936.

Mr. Vaughan serves on the Council of the Royal Institute of Chemistry, and is also a Member of Council of the Sheffield Metallurgical Association.

Clifford Whalley, B.Sc., A.R.I.C.—Senior Analyst at the Paint Research Station, Teddington. Mr. Whalley graduated, with Honours, in the School of Chemistry, University of Sheffield, in 1939 and joined the Naval Ordnance Inspection Department, Bragg Laboratory, as an Analytical Chemist. He accepted his present appointment in January 1947.

K. Balajiva, Ph.D.—Research Metallurgist at Messrs. William Jessop & Sons, Ltd. Dr. Balajiva received a scholarship of the Siamese Government which enabled him to take up his studies in England. He obtained an Honours B.Met. degree at the University of Sheffield in 1942, and received a Ph.D. degree in 1946. His joint paper with Dr. Vajragupta results from researches on slag—metal reactions, carried out for the former



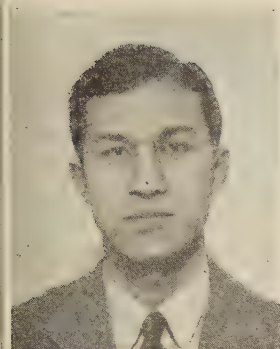
J. Glen, B.Sc.



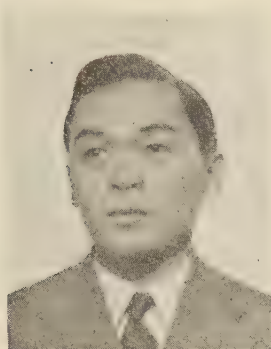
Robert Fowler



C. Whalley, B.Sc.



Dr. K. Balajiva



Dr. P. Vajragupta



Dr. H. R. Schubert

Heterogeneity of Steel Ingots Committee of the Institute.

P. Vajragupta, Ph.D.—Research worker in the Department of Applied Science, University of Sheffield. He was born at Korat, Siam, and received a scholarship of the Siamese Government, which enabled him to visit England in 1938. He received the degree of B.Sc. with Honours, in 1942, and was also made an Associate of the Royal School of Mines. He obtained his Ph.D. degree in 1946, at the University of Sheffield, where he was engaged on research on slag—metal equilibria for the former Heterogeneity of Steel Ingots Committee of the Institute.

H. R. Schubert, Ph.D.—Dr. Schubert was born in 1884, at Militsch, in Silesia. He went to the High School at Dusseldorf and subsequently to the University of Heidelberg, in 1903; later he studied History, Economics, and German Philology at the Universities of Berlin, Erlangen and Marburg, where he took his Ph.D. and M.A. in 1907. In 1909 he passed the examination enabling him to enter the Berlin Archive, and rose to become State Archive Director in 1931. In 1933 he was deprived of this position by the German Government of the day, and gradually found his way to England, where, with the help of Dr. Petersen of the Iron and Steel Institute at Dusseldorf, he was able to carry out research on the history of the iron and steel industries at the Public Records Office and the British Museum, beginning in 1937. In 1940 the University of Reading appointed Dr. Schubert Assistant in the Department of German.

Dr. Schubert's first book, dealing with the palaeography of mediaeval documents of Belgium and Holland, was published in 1908. Since that time he has written many books, articles and essays on the ancient and mediaeval history of various European countries, and he has also

written many books dealing with German industry. His book, "Das Eisenhüttenwesen im Gebiete der mittleren Lahn und des Vogelsberges bis zum Beginn der 19. Jahrhunderts," was reviewed by Dr. Desch in the Bulletin of the Iron and Steel Institute in 1939. His essay, "The First Cast-Iron Cannon made in England," was published in the *Journal* of the Iron and Steel Institute in 1942.

T. Land, M.A.—Director of Messrs. T. Land & Son, Ltd. Mr. Land was educated at Chesterfield Grammar School and at Emmanuel College, Cambridge. In 1939 he took up an appointment as Senior Physicist with Messrs. William Jessop & Sons, Ltd., and in 1945 he joined the B.S.A. Group Research Centre, also as Senior Physicist. He left the Centre in 1946 to form his own company, specializing in scientific and industrial instruments.

R. J. Sarjant, O.B.E., D.Sc.—After taking an Honours Degree in Chemistry at the Royal College of Science, Dr. Sarjant studied Fuel Technology and Chemical Engineering in the Department of Chemical Engineering of the Imperial College. In 1918 he was appointed Fuel Technologist in the Research Department of Messrs. Hadfields, Ltd., Sheffield. Later he became a Local Director, and the Head of the Research Department of the Company. Recently he was appointed Professor of Fuel Technology in the University of Sheffield.

In his earliest research work he was associated with Professor W. A. Bone. He has published many scientific papers, a number of the earliest being in collaboration with Sir Robert Hadfield. His scientific work has covered a wide field in fuel technology, metallurgical practice and refractories.

He is a member of the Fuel Efficiency Committee of the Ministry of Fuel and Power, and of many research committees of the British Iron and Steel Research Association, and other bodies. He is at present Chairman of the Yorkshire Section of the Institute of Fuel.

D. Knowles, Assoc. Met., F.I.M.—Metallurgist in the Research Department of Messrs. Hadfields, Ltd., Sheffield. He joined the technical staff in 1920 and shortly afterwards became assistant investigator in moulding-sand research. This work was later extended to cover works problems in refractories, furnace practice and pyrometry.

Mr. Knowles received his technical education at the University of Sheffield, where he obtained an Associateship in Ferrous Metallurgy in 1926. In 1942 he was elected a Member of the Iron and Steel Institute; he is a Fellow of the Institution of Metallurgists and a member of the British Foundrymen's Association and the British Ceramic Society.

Much of his experimental work on refractories and furnace practice has been incorporated in papers to the Iron and Steel Institute and to the Ceramic Society.

THE INSTITUTE OF METALS

May Lecture, 1947

A cordial invitation has been received for Members of the Iron and Steel Institute to be present at the annual May Lecture of the Institute of Metals. This is to be delivered by Sir Wallace Akers, C.B.E., a Director of Imperial Chemical Industries, Ltd., on "*Metallurgical Problems involved in the Generation of Useful Power from Atomic Energy*," at the Institution of Civil Engineers, Great George Street, S.W.1, on Wednesday, 21st May, 1947, at 6.0 P.M. Tickets for admission are not required.

THE ENGINEERING AND MARINE EXHIBITION

The Exhibition, formerly known as the Shipping, Engineering and Machinery Exhibition is to be revived in 1947, and will be held during August and September in the Grand, and National Halls, Olympia.

The Organizers have extended, to all Members of the Institute, an invitation to visit the Exhibition, and requests for complimentary tickets should be made to the Secretary as soon as possible.

TRANSLATION SERVICE

Since the announcement made in the March issue of the *Journal* (see page 452), further translations have been put in hand and the following are now available or in course of preparation. •

TRANSLATIONS AVAILABLE

No. 306 (Russian). V. A. MOJAROV: "The Use of Oxygen for Steelmaking in Reverberatory Furnaces." (*Kislород*, 1946, No. 1, pp. 1-14).

CHARGES FOR COPIES OF TRANSLATIONS: For the above translations a charge will be made of 10s. for the first copy and 5s. for each additional copy of the same translation. Requests for translations should be accompanied by a remittance. The above translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST: Members requiring translations of foreign technical papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the series.

TRANSLATIONS IN COURSE OF PREPARATION

(Swedish). B. D. ENLUND: "Recent Swedish Investigations on the Ageing of Steel." (*Jernkontorets Annaler*, 1946, vol. 130, No. 10, pp. 553-573).

(German). F. KÖRBER and W. OELSEN: "The Action of Carbon as a Reducing Agent in the Reactions of the Steelmaking Processes with Acid Slags." (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1935, vol. 17, No. 4, pp. 39-61).

(Swedish). S. MÖRTSELL: "Rationalization in Swedish Iron-Ore Dressing." (*Jernkontorets Annaler*, 1946, vol. 130, No. 9, pp. 369-460).

ABSTRACTS OF CURRENT LITERATURE *and* BOOK REVIEWS



IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

The Exploitation of Manganese Minerals. W. Steiner. (Von Roll Werkzeitung, 1945, vol. 16, July, pp. 94-99). Information on the occurrence of manganese ore in Switzerland is given. The content of manganese varies between 12% and 48%, but mining is not economic except in war-time when foreign ores are difficult to obtain.—R. A. R.

Mining Manganese Ores. W. Steiner. (Von Roll Werkzeitung, 1945, vol. 16, Sept., pp. 114-120). A brief account of the manganese-ore resources of Switzerland is given. Generally speaking it does not pay to work the Swiss ores except in war-time when other sources of supply are cut off. A very small deposit of ore containing 47.7% of manganese was found in 1945.—R. A. R.

Lake Superior Iron Ore Reserves for the Future Operation of the U.S. Iron and Steel Industry. G. W. Hewitt. (Blast Furnace and Steel Plant, 1946, vol. 34, Nov., pp. 1383-1392, 1407). Tables are presented which contain statistics on: The

tonnage and analyses of iron ores mined in the Lake Superior region of the United States since 1892; the methods by which these ores were mined; and estimates of the ore reserves. For the purposes of taxation, the reserves of high-grade ore in 1946 were stated to be 1,200,000,000 tons, which is equivalent to 15 years' supply at the rate of consumption for that year. A study of the way in which the estimates of ore reserves have increased because of improved mining techniques permitting the exploitation of more deposits leads the author to suggest that the actual reserves of normal-grade ore may be 35-50% more than those officially estimated. Even so, it is doubtful if more than 25 years' supply remains to be exploited, and a planned programme for developing the use of the associated taconite and lean-ore deposits ought to be worked out as soon as possible.—C. O.

The World's Iron Supply. R. Durrer. (Von Roll Werkzeitung, 1945, vol. 16, Sept., pp. 113-114). The distribution of the world's resources of iron ore is briefly reviewed. It is estimated that iron-bearing minerals sufficient for several

hundred years are available. If iron quartzite and titanium-bearing iron sands are included, the resources are practically limitless.—R. A. R.

The Iron Ore Resources of Switzerland. H. Fehlmann. (Von Roll Mitteilungen, 1945, vol. 4, June, pp. 5-12). A comprehensive survey of the iron ore resources of Switzerland was completed in 1937. This led to the discovery of the Fricktal deposits of oolitic ore containing about 28% of iron, the estimated reserves amounting to 50,000,000 tons. This ore can be reduced in low-shaft electric furnaces without having to sinter it.—R. A. R.

Russia Opens New Mines to Supply Kuznetsk Steelworks. A. Mikhailov. (Steel, 1946, vol. 119, Dec. 16, pp. 104-107). A short history of the Kuznetsk steelworks, in Siberia, is given. Roads and railways are being constructed to assist in the development of deposits of magnetite, cobalt, alunite, and barytes found in Upper Dashkesan, to supply the Kuznetsk works.—C. O.

PRODUCTION OF STEEL

Oxygen in Liquid Open-Hearth Steel—Effect of Special Additions, Stirring Methods and Tapping. T. E. Brower and B. M. Larsen. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2076: Metals Technology, 1946, vol. 13, Oct.). An account is given of the changes in the quantity $\Delta[\text{O}]$ (defined as the excess oxygen beyond that which would be in equilibrium with carbon in the presence of carbon monoxide at a pressure of 1 atm.) brought about by adding spiegel or crop ends, by stirring, or by tapping steel from a bath of steel. The means commonly adopted for stirring, such as the addition of sand or silica, lime with fluorspar, crop ends, and spiegel, reduce the excess oxygen only temporarily and are not of special value in controlling the final oxygen content of steel. During tapping, $\Delta[\text{O}]$ tends to decrease, with a simultaneous decrease in carbon content, apparently because of the formation of bubbles by the movement of the metal over the refractory surface around the tap-hole. In steels with more than 0.40% of carbon, the metal entering the ladle is deoxidized sufficiently to reduce the total oxygen content to less than 0.01%. As the oxygen content in the stream of heats "blocked" with ferrosilicon is not lower than this on the average, at least for carbon contents of more than 0.2%, it appears that blocking in the furnace serves no useful purpose in reducing the oxygen content.—C. O.

Control of Quality in Steel Manufacture. A. O. Schaefer. (Metal Progress, 1946, vol. 50, Nov., pp. 815-819, 822). A review is made of methods adopted in steelworks for ensuring uniformity in quality of steel, and an account is given of the tests used in determining this quality.—C. O.

Steelmaking as It Affects Properties of Interest to the User. C. H. Herty, jun. (Metal Progress, 1946, vol. 50, Nov., pp. 809-814, 826). A general account is given of the way in which the properties of steel may be influenced by steelmaking practice. The factors chiefly discussed are chemical composition of the steel, slag control, deoxidation, and rolling-mill operations.—C. O.

Killed Bessemer Steel for Seamless Tubes E. C. Wright. (Metal Progress, 1946, vol. 50, Oct., pp. 662-664). A general account is given of a process for the deoxidation of heats of steel in Bessemer converters by the addition of molten pig iron. The charge is blown until the carbon flame drop, and a weight of pig iron is added containing sufficient carbon to deoxidize the heat and leave the required analysis. The normal ferromanganese, ferrosilicon, and aluminium additions are made in the ladle. Steels of high yield point and tensile strength and good elongation for the manufacture of seamless tubes have been produced by this process during the last seven years.—C. O.

Ingot Mould Practice. M. Charmeau. (Association Technique de Fonderie: Foundry Trade Journal, 1946, vol. 80, Nov. 28, pp. 325-326, 324). The essential properties and typical defects of ingot moulds are discussed. Details are given of experience with moulds of several different compositions at the Le Creusot steelworks. Open-grain irons apparently gave the best results, and additions of titanium and vanadium, or chromium and titanium proved beneficial in prolonging the life of moulds.—C. O.

FOUNDRY PRACTICE

The Reciprocal Effects of Progress in Automobile and Foundry Techniques. J. Bouchet. (Fonderie, 1946, vol. 1, Jan., pp. 12-26). The way in which the desire to improve the internal combustion engine has stimulated the production of better cast iron and cast steel is discussed and details of the properties of modern cast iron and cast steel are given.—R. A. R.

Carburizing in the Cupola. H. S. H. Ritzen. (Metallen, 1946, vol. 1, Nov., pp. 45-47). (In Dutch). Carburization of the iron in the cupola is affected by the coke, the slag, the temperature, the reaction time, and the composition of the charge. These factors are discussed.—R. A. R.

Current Problems in Charging Cupolas. A. Collaud. (Verband schweizerischer Eisengiessereien: Von Roll Mitteilungen, 1943, vol. 2, Oct., pp. 57-70). War-time difficulties in cupola operation in Switzerland are reviewed with special reference to those caused by too much sulphur and moisture in the materials charged. Several examples of castings with hydrogen blowholes are described.—R. A. R.

Control in a Mechanised Jobbing Steelfoundry. D. Brown. (Institute of British Foundrymen: Foundry Trade Journal, 1946, vol. 80, Dec. 26, pp. 421-426, 430). The various production processes in a mechanized jobbing steel foundry are outlined and the control methods used in order to obtain the maximum benefit from mechanization are described.—J. R.

The Side-Blown Converter in the Postwar Period. A. W. Gregg. (Foundry, 1946, vol. 74, Nov., pp. 74-76, 158-161). The recent increase in the number of converters installed in steel foundries in the United States is discussed. After examining the relative merits of side and bottom blowing, the author concludes that the side-blown converter will find its main applications in the future in: (1) Iron foundries, for producing high-strength iron by blending with cupola metal; (2) steel mills, as a competitor of the usual Bessemer process; (3) and the duplex and triplex processes, in conjunction with cupolas and electric furnaces.—C. O.

Core Sand—Purchasing Factors. H. Louette, A. E. Murton, and H. H. Fairfield. (American Foundryman, 1946, vol. 10, Oct., pp. 63-66). A short account is given of an investigation of the effects of shape and size-distribution of sand grains upon the properties of two core sands. The rounded sand grains had many advantages over the angular grains; less core-oil was needed; the baked core strength was higher, and the surface finish of castings was smoother.—C. O.

Drying of Foundry Sand Cores by Dielectric Heat. J. R. Calhoun, L. E. Clark, and H. K. Salzberg. (Industrial Ovens: Foundry Trade Journal, 1946, vol. 80, Dec. 19, pp. 405-406, 410). The principles of dielectric heating are outlined and its application to the drying of sand cores is discussed. Among the advantages claimed for this method of heating is a considerable saving in drying time.—J. R.

How Much Venting Power Must Green Sand Molds Possess? E. C. Troy. (Foundry, 1946, vol. 74, Dec., pp. 82-85, 215-220). The question of whether gas pressure at mould surfaces is responsible for many of the defects generally attributed to it is discussed at length. In the author's opinion the danger from moisture in ordinary green-sand practice has been over-emphasized, and many of the precautions now taken to ensure adequate venting are unnecessary.—C. O.

Cement Used for Foundry Moulds. L. Maillard. (Fonderie, 1946, vol. 1, Jan., pp. 5-11). A description is given of the making of sand-cement moulds by the Randupson process, with several illustrations of a large foundry at which the method is used.—R. A. R.

The Bonding Action of Clays. Part II—Clays in Dry Molding Sands. R. E. Grim and F. L. Cuthbert. (University of Illinois, 1946, Engineering Experiment Station Bulletin Series No. 362). The fundamental study of the structure and properties of moulding sands which was begun in Part I of this paper (*see* Journ. I. and S.I., 1945, No. II, p. 159A) is continued, with particular reference to the action of clays in dry moulding sands. Data are presented showing the relationships between the dry-compression strength of sands and the amounts of water and montmorillonite, halloysite, illite, or kaolinite clay present in them. Theories of dry-compression and "air-set" strengths are discussed.—C. O.

Influence of Design and Pattern-Making on Foundry Technique. T. H. Sneddon. (Institute of British Foundrymen: Foundry Trade Journal, 1946, vol., 80, Dec. 12, pp. 365-368; Dec. 19, pp. 393-396; Dec. 26, pp. 427-429). An account is given of the design of patterns for the production of unorthodox castings at a reasonable price. The first part of the article deals with the use of strickles in shaping circular moulds, and with patterns and core boxes for heavy and medium steel castings when only a limited number are required. The remainder of the article deals with particular examples of jobbing, semi-repetition, and repetition work in a steel foundry producing castings weighing from 1lb. to 7 cwt.—C. O.

Pattern Rigging for Production Molding. F. C. Riecks. (Foundry, vol. 74, 1946, Dec., pp., 111, 234-236). The use of automatic machines for producing sand moulds for high rates of production of steel castings is discussed, with examples taken from the practice of the Ford Motor Company.—C. O.

Mold Coatings. C. R. Funk. (Blast Furnace and Steel Plant, 1946, vol. 34, Oct., pp. 1251-1256). The physical and chemical properties of materials used for the coating of moulds are discussed, and details are given of the individual characteristics of coal tar, graphite, aluminium, sugar, and pitch.—c. o.

Steel Castings Produced Centrifugally. E. Bremer. (Foundry, 1946, vol. 74, Nov., pp. 78-81, 194-196). The centrifugal-casting equipment of the Youngstown Alloy Casting Corporation, Ohio, is illustrated and briefly described. Castings are made in wear- and heat-resisting steels, and in plain carbon steels by true centrifugal casting, in which the machine and the casting rotate about the same axis, and "centrifuging," in which the moulds are arranged radially around the sprue at the centre of rotation of the machine. In both cases rotation is produced by hydraulic power.—c. o.

Continuous Casting of Metals in Germany. (British Intelligence Objectives Sub-Committee, 1946, F.I.A.T. Final Report No. 876: H.M. Stationery Office). A brief account is given of the use in Germany of two continuous casting processes, the Junghans and the VLW (Vereinigte Leichtmetall Werke, Hanover). At the end of the war a Junghans plant for the continuous casting of steel was nearing completion; experiments had been made to cast steel by both processes, but difficulty was experienced in obtaining good surface finish.—c. o.

HEAT-TREATMENT

AND HEAT-TREATMENT FURNACES

Rapid Case-Hardening Steel. (Steel, 1946, vol. 119, Nov. 4, pp. 100, 146). A very brief description is given of the Chapmanizing process for nitriding steel in a liquid bath containing active nitrogen gas. Cases of from 0.002 to 0.035 in. in depth can be formed in 4 hr.—c. o.

Liquid Carburizing. R. S. Komarnitsky. (Metal Progress, 1946, vol. 50, Oct., pp. 665-669). An illustrated description is given of the operation of a process for carburizing steel by immersion in cyanide salt baths at temperatures between 1550° and 1750° F. Deep cases of high carbon and low nitrogen content are produced by the decomposition of sodium cyanide in the presence of alkaline-earth catalysts.—c. o.

Potential Hazards in Molten Salt Baths for Heat Treatment of Metals. (National Board of Fire Underwriters Research Report No. 2,

1946). A detailed review is made of the dangers of fires and explosions involved in the use of molten salts for the heat-treatment of metals and alloys. The causes of typical accidents such as nitrate explosions, structural failures, and admixture of cyanides are analysed, and recommendations for precautionary measures are made.—c. o.

Salt Baths for Hardening High Speed. W. E. Bancroft. (Metal Progress, 1946, vol. 50, Nov., pp. 941-947). The applications and limitations of molten-salt baths for the hardening of high-speed tool steels are discussed. Data are given on equipment and handling methods, salt-bath compositions, and the operation and maintenance of baths.—c. o.

High Frequency Induction Heating. E. May and T. G. Tanner. (Journal of the Institution of Production Engineers, 1946, vol. 25, Dec., pp. 331-352). An account of equipment for and applications of high-frequency induction heating, including melting, surface-hardening and through-heating is given. The theory of induction heating is explained.—R. E.

The Resistance of Metals to Scaling. B. Lustman. (Metal Progress, 1946, vol. 50, Nov., pp. 850-860). The theory of the nature of scaling on metals is outlined, with references to the literature. The basis of the heat-resisting properties of each of the following group of alloys is explained: Chromium-iron; chromium-nickel; nickel-chromium-iron; aluminium-iron; aluminium-chromium-iron; silicon-iron and silicon-chromium-iron; and copper base. An appendix contains data on the dissociation pressures of oxides formed on various solid metals.—c. o.

Pressure Vessels Treated in Car-Type Stress-Relieving Furnace. W. Helme. (Industrial Heating, 1946, vol. 13, Oct., pp. 1606-1610). A large gas-fired car-type furnace built at Chicago, Illinois, for the stress-relieving heat-treatment of welded pressure vessels is described. Vessels up to 83 ft. long and 13ft. 6in. in dia. can be stress-relieved in a single heat in this furnace, the maximum operating temperature of which is 2000° F.—c. o.

Heat Treatment. (Automobile Engineer, 1946, vol. 36, Dec., pp. 573-582). General illustrated descriptions are given of electric heat-treatment furnaces and handling equipment manufactured by G.W.B. Electric Furnaces, Ltd., Dudley.—c. o.

The Use of Box-Type Furnaces for Tools. E. F. Watson. (Machinery, 1946, vol. 69, Dec. 26, pp. 818-819). A short description of electrically

heated box-type furnaces which may be used for preheating and hardening tools is given, together with details of the gaseous atmosphere commonly used in such furnaces.—C. O.

Fundamentals of Annealing Low Carbon Steel. G. Sachs, L. J. Ebert, G. B. Kasik, and F. J. Nejedlik. (Iron and Steel Engineer, 1946, vol. 23, Nov., pp. 88-98). A detailed account is given of an experimental study of the factors which determine the properties of annealed low-carbon steel strip. The results, in the form of graphs and photomicrographs show the effects of cold-work on hardness and recrystallization, of annealing time and temperature on hardness and tensile strength, of annealing temperatures and cooling rates on ageing and hardenability, and of cooling rates on mechanical properties.—C. O.

Induction Hardening of Armor. T. Bishop. (Metal Progress, 1946, vol. 50, Nov., pp. 955-958). An account is given of equipment developed at the Dortmund-Hoerder works in the Ruhr district, for the surface-hardening of armour plate by electrical induction methods. A structure consisting of homogeneous martensite for a definite distance below the surface, with a gradual transition into the sorbite of the unaffected base metal is produced by the low-frequency (40-600 cycles/sec.) currents which were used. The equipment can harden plates up to 7 ft. wide, 24 ft. long, and 16 in. thick at a rate of 8 in. per min., giving a hardened layer up to $2\frac{3}{4}$ in. in thickness.—C. O.

The Manufacture of Homogeneous Light Armor. (Combined Intelligence Objectives Sub-Committee, 1946, File No. XXVII-99: H.M. Stationery Office). This report covers the manufacture by Stahlwerke Röchling-Buderus A.G., Wetzlar, of 3-15 mm. thick homogeneous armour plate. The steel was made in an electric furnace to the following analysis: Carbon 0.45%, manganese 1.0%, and silicon 1.5%. It was heat-treated to a hardness of 460 Brinell.—R. A. R.

Bright Hardening Stainless Steel. (Steel, 1946, vol. 119, Nov. 25, pp. 80-81). The heat-treatment of stainless steel in cracked ammonia atmospheres is described briefly.—C. O.

FORGING, STAMPING, DRAWING, AND PRESSING

Steel Can be Guerinised Too. (Machinist, 1946, vol. 90, Nov. 30, pp. 1374-1375). A short

account is given of the application to the shaping of steel of the Guerin process for forming aluminium sheet on presses equipped with rubber pads. At the Douglas Aircraft works, corrosion-resistant steel sheets 0.016-0.050 in. in thickness, and motor-car-body steels up to 0.156 in. in thickness have been formed successfully with rubber blocks.—C. O.

Shortcuts in Spring Manufacture. (Steel, 1946, vol. 119, Nov. 25, pp. 72-74). An illustrated account is given of the semi-automatic heat-treatment equipment at the plant of William and Harvey Rowland Inc., Frankford, Philadelphia. A machine has been devised in which spring leaves may be formed and hardened simultaneously.—C. O.

The Manufacture of Fish Hooks. (Machinery, 1946, vol. 69, Dec., pp. 822-824). The manufacture of fish hooks at the Studley Works of Needle Industries, Ltd., is described. Small hooks are made at a rate of 98/min. in automatic Schumag machines. The feeding mechanism and the operations which fashion the means of attachment to the line, raise the barb, and bend the wire to the desired hook shape are described in detail. Steps in the production of larger hooks on Russell machines at a rate of 96/min., are illustrated. After hardening and tempering heat-treatments and cleaning with dilute acid, the dried hooks may be plated, blued, bronzed, or lacquered as required.—R. L. B.

German Small Nail and Tack Manufacture. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 972: H.M. Stationery Office).—R. A. R.

One Press Operation Replaces Four. J. A. Grainger. (Machinist, 1946, vol. 90, Dec. 28, pp. 1525-1530). Detailed descriptions and diagrams are given showing how a small mild-steel tubular component is produced from a circular blank in two stages during one pressing operation.—C. O.

Practical Problems of Light Presswork Production. J. A. Grainger. (Sheet Metal Industries, 1946, vol. 23, Jan., pp. 89-94, 96; Feb., pp. 293-298; Mar., pp. 497-504; May, pp. 905-908, 912; June, pp. 1109-1116; July, pp. 1313-1319; Sept., pp. 1721-1727; Oct., pp. 1923-1930; Nov., pp. 2127-2131; Dec., pp. 2341-2349). This is continuation of a series of articles, in which many problems met with in the shallow- and deep-drawing of ferrous and non-ferrous metal sheets are dealt with. Numerous drawings of presses and dies for both simple and complicated operations illustrate the recommendations made.—R. A. R.

ROLLING-MILL PRACTICE

Operation of 44-in. Blooming Mill in South African Plant Conforms to Latest Practice. (Blast Furnace and Steel Plant, 1946, vol. 34, Oct., pp. 1265-1270). The modern 44-in. blooming mill at the Iscor Works of the South African Iron and Steel Industrial Corporation, Limited, Pretoria, South Africa, is described and illustrated. The mill, with a monthly production of 48,000 ingot tons, is similar in design and operation to blooming mills recently installed in the United States.—C. O.

Cold-Reduction Reversing Strip Mill. (Engineer, 1946, vol. 182, Nov. 29, p. 483). **New 80-in. Cold Reduction Reversing Strip Mill.** (Iron and Coal Trades Review, 1946, vol. 153, Nov. 22, p. 935). **The New 80-in. Cold Reduction Reversing Strip Mill of John Summers & Sons, Ltd.** (Metallurgia, 1946, vol. 35, Nov., pp. 38-40). **John Summers & Sons Expansion Programme.** (British Steelmaker, 1946, vol. 12, Dec., pp. 590-595). **Increasing Strip Capacity.** (Iron and Steel, 1946, vol. 19, Dec., pp. 793-795). **80-in. Cold-Reduction Reversing Strip Mill.** (Sheet Metal Industries, 1946, vol. 23, Dec., pp. 2335-2336). The new 80-in. cold-reduction strip mill installed at Shotton, Chester, is described briefly. The mill is of the 4-high reversing type, designed to cold-reduce hot-rolled, pickled strip up to 74 in. in width, at a speed of 500-1000 ft./min. Coils up to 10 tons in weight can be handled.—C. O.

Production of Seamless Metallic Pyrometer Sheaths and Electric Resistance Alloys by Heraeus Vacuumschmelze A.G., Hanau a./M. and at Sterbfritz. (British Intelligence Objectives Subcommittee, 1946, Final Report No. 779: H.M. Stationery Office). The melting and rolling of nickel-chromium and iron-chromium-aluminium alloys in the production of pyrometer sheaths and electrical resistance wire and strip in factories at Hanau and Sterbfritz are described.—C. O.

Employs Stretch Principle in Steel Tube Production. (Steel, 1946, vol. 119, Nov. 25, p. 96). The use of the "stretch reduction" principle in the continuous seamless-tube mill at Lorain, Ohio, is discussed. "Stretch reduction" involves the introduction of tension by increasing the relative speed of rolls in successive stands more than is required merely to roll the tube to a smaller diameter.—C. O.

Ball Bearings—Notes on Production of Ball Tubing at Deutsche Edelstahlwerke A.G., Krefeld, and Production of Ball Races at Kugelfischer A.G., Schweinfurt. (British Intelligence Objectives Sub-

Committee, 1946, Final Report No. 884: H.M. Stationery Office).—C. O.

Problems Relating to the Permanent Deformation of Rectangular Bars by Bending. A. Geleji. (Royal Hungarian Palatine-Joseph University, Publications of the Department of Mining and Metallurgy, 1943, vol. 15, pp. 225-245). A solution is offered to the problem of calculating the bending moment necessary to produce a given permanent deformation in a rectangular bar resting on two supports. Calculations of the power requirements of plate-bending machines are also made.—R. A. R.

WELDING AND FLAME-CUTTING

A Method for Determining the Applicable Welding Procedure for Steels. B. Ronay. (Welding Journal, 1946, vol. 25, Nov., pp. 736-s-747-s). A description, with illustrations and micrographs, is given of tests performed during the development of a method for producing, without welding, the heated-affected zone which arc-welding causes. In the method finally evolved, a band $\frac{1}{4}$ -in. in width in the centre of a $\frac{3}{8} \times 1\frac{1}{2} \times 8$ -in. bar is heated by a high-frequency induction coil. By this means the changes in structure brought about by preheating, post-heating, and the welding passes may be simulated. The brittleness of the steel after the heat-treatment is measured by a notch-bend test, employing plungers of graduated radii.—C. O.

Miniature Electric "Furnace". (Steel, 1946, vol. 119, Nov. 25, pp. 70-71, 82-85). An illustrated description is given of a shielded-arc electrode designed for automatic welding. The heavy flux-coating, which is consumed at a lower rate than the electrode metal during welding, forms a "crucible" around the arc.—C. O.

A Safety-Type Electrode Holder. (Overseas Engineer, 1947, vol. 20, Jan., pp. 186). A brief description is given of a simple, robust electrode holder designed to eliminate the risk of shock when using A.-C. current in welding. The body of the holder is made of a tough insulating material, and incorporates a contact-breaking mechanism which enables a full welding current of up to 300 amp. to be broken without severe arcing. Electrodes can only be withdrawn and inserted when the switch lever is in the safety position.—C. O.

Extruded Powder Metal Welding Rods. F. C. Kelley and F. E. Fisher. (Iron Age, 1946, vol. 158, Dec. 19, pp. 68-72). A process for producing welding rods of 18/8 steel from a mixture of powdered metals by extrusion is described in

detail. The extrusion mixture consists of low-carbon ferrochromium, annealed electrolytic iron, electrolytic nickel and manganese, dry starch, and water. After extrusion, the rods are annealed at 2730° F. in a current of dry hydrogen, the final carbon content being 0.05–0.09%. The welding characteristics of the rods are very satisfactory, but the cost of the process at the moment is too high to permit competition with other forms of rod production.—C. O.

Inert Arc Welding. D. W. Puffer. (Steel, 1946, vol. 119, Nov. 18, pp. 80–82, 116, 119). The process of welding under a protective envelope of inert gas is described briefly. Heat is generated by an electric arc established between a tungsten electrode and the metal to be welded. Filler metal may be used if required, but no flux is necessary. In welding stainless steel by this process, direct current is usually employed, with the electrode negative, and an argon or helium atmosphere.—C. O.

The Atomic Hydrogen Welding Process. W. P. Brotherton. (Steel Processing, 1946, vol. 32, Aug., pp. 511–514). The application of atomic-hydrogen welding to the joining of thin stainless-steel sheets for the aircraft industry is discussed. The reducing atmosphere of hydrogen surrounding the welds is of great importance in the prevention of weld decay. The speed of welding with atomic hydrogen is about twice that with oxy-acetylene, and there is a corresponding decrease in cost.—C. O.

Weldability of Malleable Cast Iron. T. J. Palmer. (Transactions of the Institute of Welding, 1946, vol. 9, Dec., pp. 183–188). After describing the methods of producing white-heart and black-heart malleable cast iron and their microstructures the difficulty of welding them by ordinary methods is explained. To avoid brittle structures the welding temperature must not exceed about 980° C. Suitable bronze welding rods are described; these contain some silicon and often nickel, whilst lead and phosphorus are detrimental. The welding groove can be prepared by any convenient mechanical method except grinding; flame-cutting is unsuitable. A borax/boric-acid type of flux is suitable.—R. A. R.

Arc Atmospheres and Underbead Cracking. M. W. Mallett and P. J. Rieppel. (Welding Journal, 1946, vol. 25, Nov., pp. 748-s–759-s). A detailed description is given of an investigation into the effects of gaseous atmospheres upon welding-arc characteristics and the properties of weld metal. It was found that there is a correlation between the hydrogen in the arc atmosphere, the hydrogen content of the weld

deposit, and the incidence of underbead cracking in the alloy-steel parent metal. No cracking was experienced with atmospheres containing no hydrogen or when using lime-coated ferritic electrodes which evolved gases containing only 10% of hydrogen. Metal arcs were relatively stable in synthetic atmospheres of carbon dioxide and carbon monoxide, but the presence of even small percentages of hydrogen tended to make the arcs erratic. The atmosphere which gave the best welding characteristics was a mixture of carbon monoxide and carbon dioxide in equal proportions.—C. O.

Effect of Certain Block and Other Special Welding Procedures on Residual Welding Stresses. F. Jonassen, J. L. Meriam, and E. P. DeGarmo. (Welding Journal, 1946, vol. 25, Sept., pp. 492-s–496-s). The results of measurements of the residual stresses in butt-welds in 1-in. low-carbon steel ship plates are reported. Longitudinal residual stresses were below 35,000 lb./sq. in. when double-V joints were block-welded in lengths of from 4 to 5 in., the blocks being deposited in special sequences. Butt-welds made by a “cascade” procedure, in which each 4-in. pass extended from the bottom of a single-V groove to the top of the groove at a slope of 1 in 4, had longitudinal residual stresses somewhat lower than those of ordinary welds.—C. O.

Influence of Magnetic Materials on the Welding Characteristics of Resistance Welding Machines. J. J. Riley and C. E. Smith. (Electrical Engineering, 1946, vol. 65, Dec., pp. 852–860). An investigation into the degree of reduction of the welding current caused by the introduction of sheet steel into the throat of a resistance-welding machine is described. The change in current was evaluated from measurements of the reactive and resistive voltage components caused by the introduction of the steel into the magnetic field, and from a knowledge of the short-circuit impedance constants of the welding machine. The effect of magnetic material in reducing the welding current is a function of the thickness and width of the sheets, and of the secondary resistance circuits of the welding apparatus. Numerical examples of the evaluation of the reactive and resistive voltage components and the application of the data to specific problems are included in two appendices.—C. O.

PROPERTIES AND TESTS

Electric Steel Sheets. J. S. Vatchagandhy and G. P. Contractor. (Iron and Steel, 1946, vol. 19, Nov., pp. 591–597; Dec., pp. 798–800). See Journ. I. and S. I., 1946, No. II, p. 12A.

The P-V Test—A New Hardenability Measure. E. S. Kopecki. (Iron Age, 1946, vol. 158, Nov., pp. 66–69). A method of determining the hardenability of sheets of low and medium hardenability, called the “penetration-velocity” or “penetration V-shape” test, is described and illustrated. The test-piece is formed by making two cuts on opposite sides of a bar of the steel, at 45° to the longitudinal axis of the bar, giving a chisel edge with an angle of 90°. The specimen, 1½ in. in length, is quenched in a special fixture by a water spray, and then sectioned at right angles to the chisel edge to allow hardness measurements to be made. The test is inexpensive, accurate and reproducible.—C. O.

Contribution on the Quality Rating of Grey Cast Irons According to Their Mechanical Properties and on the Improvement of Their Behaviour in Service. A. Collaud. (Von Roll Mitteilungen, 1944, vol. 3, No. 1–2, pp. 1–98). The author explains how the fundamental properties of grey cast iron are influenced by the physico-chemical composition of the material, by the structure, by the rate of cooling, by subsequent heat-treatment, etc., and discusses the possibility of improving the properties. The subject matter is dealt with under the following headings: I—Introduction; II—The anisotropy of structure and of mechanical properties of grey cast irons to Swiss specifications; III—The internal stresses in grey iron castings and their elimination by a stabilizing anneal; IV—A critical study of the behaviour of grey cast irons subjected to mechanical stresses (behaviour of cast iron in tensile test, Hooke's law, and variation of hysteresis on repeated stressing as a function of the stress are among the matters considered); V—The bend test and the behaviour of grey cast irons subjected to mechanical stresses (four characteristics, of rigidity, of ductility, of toughness, and of strength, are defined and determined from bend-test observations); VI—A study of the factors of composition and structure which influence the behaviour of grey cast irons when subjected to static mechanical stresses.—A. E. C.

The German Permanent Magnet Industry. (British Intelligence Objectives Sub-Committee, 1946, Final Report No. 717: H.M. Stationery Office). A survey is made of the economic structure of the permanent magnet industry in Germany, with details of past and present production and of technical developments made during the war.—C. O.

The Statistical Aspect of Fatigue of Materials. A. M. Freudenthal. (Proceedings of the Royal Society, 1946, vol. 187, Dec. 13, pp. 416–429).

On the formal assumption of the existence of a statistical distribution function of the separation strength of cohesive bonds, many of the experimentally determined relationships between the variables involved in fatigue or “progressive failure” are theoretically deduced by applying the fundamental rules of the theory of probability.—C. O.

X-Ray Diffraction Study of the Effect of Residual Compression on the Fatigue of Notched Specimens. J. T. Norton, D. Rosenthal, and S. B. Maloof. (Welding Journal, 1946, vol. 25, Nov., pp. 729-s–735-s). A report is given of a study of the rôle of residual compression in fatigue failure. By loading notched test bars in tension, residual compressive stresses were induced without appreciable work-hardening. The amount and distribution of the residual stresses were measured by X-ray diffraction methods. The fatigue life of the specimens was noticeably improved, the degree of improvement depending upon the stress pattern remaining after the first few fatigue cycles.—C. O.

Strengthening Metal Parts by Shot Peening. H. F. Moore. (Iron Age, 1946, vol. 158, Nov. 28, pp. 70–76; Dec. 5, pp. 81–86). Fatigue failure in metals and the effect of shot-peening on fatigue are discussed at length. An explanation of the function of shot-peening in strengthening metals is proposed, based on a consideration of fatigue test results. The second part of the article deals with the peening of regions of high compressive stress, such as the neighbourhoods of holes, fillers, and notches, and the precautions which must be observed to obtain the optimum results from shot-peening.—C. O.

Pre-Stressing of Metals and Metal Parts. (Materials and Methods, 1946, vol. 24, Nov., pp. 1156–1159). A review is given of the work performed by J. O. Almen on the pre-stressing of metals, especially by shot-peening. The remarkable increases in fatigue life which have been obtained by pre-stressing treatments have brought about important changes in the design of metal parts.—C. O.

Shot Peening of Agricultural Hand Tools. (Steel Processing, 1946, vol. 32, Oct., pp. 661–662). A brief account is given of improvements in the useful life of implements such as shovels and forks brought about by change of design and the use of shot-peening.—C. O.

Notes on the Static Testing of Welds. A. Schleicher and J. A. Verö. (Royal Hungarian Palatine-Joseph University, Publications of the Department of Mining and Metallurgy, 1943, vol. 15, pp. 171–205). Tensile and hardness tests were

made on specimens cut from welded joints in mineral-oil and natural-gas pipe lines of steel containing 0.3% max. of carbon. Hungarian and German testing procedures were employed and the former specifications were found to be too rigid.—R. A. R.

Ductility of Metals and Alloys Used in Construction. G. Welter. (*Metallurgia*, 1946, vol. 34, Sept., pp. 233–237; Oct., pp. 304–310; vol. 35, Nov., pp. 33–36). An investigation is recorded in which plain and notched specimens of steel, light metals and alloys were tested under axial and eccentric tensile loads. Eccentricities up to $\frac{1}{2}$ -in. seem to have no harmful influence on standard specimens of mild steels whilst light alloys and brass are not ductile enough to stand these critical conditions. In brittle materials such as cast iron there appeared to be a closer relationship between the ultimate strength and the degree of eccentric loading. Stress-strain curves for materials in the as-received, cold-stretched, and annealed conditions, tested with various eccentricities, showed that for eccentrically loaded notched specimens, very ductile materials behave almost as well as they would under axial loading, whilst less ductile and brittle materials rapidly lose their ultimate strength.—R. A. R.

The Separation of Principal Stresses in Photo-Elastic Analysis. E. K. Frankl. (*Journal of the Royal Aeronautical Society*, 1946, vol. 50, Dec., pp. 974–984). Fourteen analytical, graphical, and experimental methods for the separation of the principal stresses from the photo-elastic stress pattern are discussed and a number of them described in detail. Their usefulness from the point of view of the practical stress analyst is considered.—R. E.

The Brittle Lacquer Method for Estimating Stress Distribution in Welded and Riveted Joints. R. F. Tylecote. (*Sheet Metal Industries*, 1946, vol. 23, Nov., pp. 2194–2198). The use of coatings of brittle lacquer in the analysis of stresses on metallic surfaces is described. The directions of the principal tensile and compressive stresses are indicated by the strain lines and cracks which appear in the lacquer when the strain exceeds a certain value. The stresses around rivets and welds in aluminium sheets under load were investigated by this method. It was found that in riveted joints, the main stress is rear compression; in welded joints the stress is at first tensile, acting on the front of the weld, but deformation may cause compressive stresses to act on the back; in “mixed” welded and riveted joints, the welds failed before strain lines appeared around the rivets.—C. O.

Influence of Geometrical Restraint and Temperature on the Toughness and Mode of Rupture of Structural Steel. A. R. Anderson and A. G. Waggoner. (*Welding Journal*, 1946, vol. 25, Nov., pp. 789-s–801-s). An account is given of investigations into the behaviour of $\frac{1}{4}$ -in. structural steel plates subjected to static tensions at temperatures between $+80^{\circ}$ and -80° F., and the geometrical restraints produced by various welding patterns. A specimen for testing butt-welds under bi-axial tension has been designed. It is in the form of two truncated cones joined by the weld. The latter part of the paper is devoted to an explanation of the behaviour of steels under uni-axial and bi-axial stresses at different temperatures, as shown in a series of photomicrographs.—C. O.

Porcelain Enameling Characteristics of Some Common Ferrous Metals. W. A. Deringer. (*Journal of the American Ceramic Society*, 1946, vol. 29, Nov., pp. 332–340). The enamelling characteristics of the following materials were studied: (1) a 0.10%-carbon steel; (2) steel (1) annealed in hydrogen; (3) enamelling iron; (4) titanium-bearing enamelling iron; (5) iron (4) after carburizing; (6) a 5%-chromium steel; (7) 18/8 stainless steel. The enamelling characteristics depend on the degree of diffusion of atomic hydrogen and are independent of the carbon content and the stabilization by titanium.—R. A. R.

Recent Publications on the Testing of Metallic Finishes. M. B. Diggin and O. Kardos. (*Metal Progress*, 1946, vol. 50, Nov., pp. 1072–1074). Twenty-seven recent publications on the testing of metallic coatings are very briefly reviewed.—C. O.

Machinability Versus Physical Properties—An Example. M. E. Merchant. (*Metal Progress*, 1946, vol. 50, Nov., pp. 1013–1019). An explanation based on the theory of the mechanism of chip formation is given of the widely differing machining properties of two steels essentially similar in composition and microstructure. The three properties of a metal which determine its machinability are its shear strength, the coefficient of friction between the flowing chip and the face of the cutting tool, and the rate of change of the shear strength of the material with applied compressive stress. A machining test and a series of charts which enable these variables to be computed are explained.—C. O.

Supersonic Vibrations and Their Applications. E. G. Richardson. (*Journal of the Royal Society of Arts*, 1947, vol. 95, Jan. 3, pp. 90–105). The production and measurement of supersonic waves are outlined, and the applications of supersonics

in pure and applied science are discussed. An instrument for the detection of hair-line cracks in metals is illustrated.—R. E.

Screw-Driven Creep-Rupture Testing Machine. M. J. Manjoine. (Metal Progress, 1946, vol. 50, Nov., pp. 1100–1101). A brief description is given of a machine developed by the Westinghouse Research Laboratories for determining creep-rupture strength. The machine employs a motor-driven screw for applying the load, instead of the conventional lever arm and weights, and incorporates automatic recording equipment for tracing an individual creep curve for each specimen.—C. O.

Chemical Laboratory Instrumentation in Germany. (British Intelligence Objectives Subcommittee: 1946, Final Report No. 736: H.M. Stationery Office). Descriptions are given of some of the instruments and techniques used in German physico-chemical laboratories.—R. A. R.

METALLOGRAPHY

Use of Coated Lenses for Metallography. E. Walden. (Metal Progress, 1946, vol. 50, Nov., pp. 1097–1099). Photomicrographs are shown which illustrate the increased contrast and detail, and the decreased glare which are obtained by using fluoride-coated objective lenses in metallographic examinations.—C. O.

Room Temperature Casting Resin for Metallographic Mounts. G. L. Kehl and J. S. Church. (Metal Progress, 1946, vol. 50, Nov., pp. 1089–1090). Details are given of a transparent plastic developed for use in mounting metallographic specimens. No pressure is required in moulding it, and the maximum temperature need not exceed 50° C.—C. O.

A Selection of Methods for Polishing Metallographic Specimens. F. G. Anderson and R. E. McGraw. (Wire and Wire Products, 1946, vol. 21, Nov., pp. 879–883, 916, 917). A technique for polishing metallographic specimens is described. The materials required are a tin-lead alloy lap, a paraffin wheel with 600-grit abrasive, and a synthetic cloth called "Gamal". Micrographs of the excellent results obtained on ferrous and non-ferrous metals and alloys are shown.—R. A. R.

Electropolishing in Postwar Finishing. C. L. Faust. (Metal Progress, 1946, vol. 50, Nov., pp. 1068–1069). The present position of electropolishing as a metal-finishing process is discussed.—C. O.

Polishing and Buffing. H. L. Kellner. (Metal Progress, 1946, vol. 50, Nov., pp. 1070–1072). Wartime developments in buffing equipment are described.—C. O.

A Survey of Engineering Radiography. V. E. Pullin. (Engineer, 1947, vol. 183, Jan. 10, pp. 40–42). The development of the system of radiographic inspection adopted by the Aeronautical Inspection Directorate is described, and a short account is given of the equipment in general use in this country, and of the training of personnel.—C. O.

A Method of Estimating Exposure time. D. T. O'Connor. (Industrial Radiography and Non-Destructive Testing, 1946, vol. 5, No. 2, pp. 22–23). A method is described by which the exposure time necessary to produce a given film density on a radiograph may be estimated. It is based on a knowledge of the characteristic curve of film density against exposure time for the film to be used for exposures under standard conditions.—C. O.

Coalescence in Steel. N. T. Belaiew. (Iron and Coal Trades Review, 1946, vol. 153, Dec. 13, pp. 1079–1085; Dec. 20, pp. 1144–1146; Dec. 27, pp. 1189–1195; 1947, vol. 154, Jan. 3, pp. 13–18; Jan. 10, pp. 69–73; Jan. 17, pp. 69–73). This article is a translation of one which appeared in *Revue de Métallurgie, Mémoires*, Mar.–Oct., 1944. (See Journ. I. and S. I., 1946, No. I, p. 84A).—C. O.

The (111) Reflections in Rolled and Recrystallized Nickel-Iron. J. F. H. Custers. (Physica, 1941, vol. 8, July, pp. 771–788; N. V. Philips' Gloeilampenfabrieken No. 1565). The structures of an iron-nickel alloy containing 48% of nickel, in the as-rolled and annealed states, were examined by X-rays to obtain a better understanding of the (111) reflections on transmission photograms originating from those crystal fragments in the recrystallized metal which deviate in orientation from the predominating cube orientation. A certain amount of the cubic structure was found to be present in the as-rolled condition. The crystal fragments in the non-cubic position, after annealing at not too high a temperature, e.g., lower than 900° C., are not to be ascribed to twinning, nor can they be described as a superposition of the (111) and (112) orientations which form the major part of the rolling structure as given by Sachs and Spretnak. The formal description of these crystal fragments (Z-fragments) as twins, rotated 8° about an axis which is normal to the twinning (111) plane, is in excellent agreement with the experimental data. Another kind of crystal fragment in the non-cubic orientation is found even after recrystallization at 1100° C. It is identified as genuine twins having an octahedral plane in common with the cube orientation.—R. A. R.

CORROSION

Fundamental Factors on Corrosion Control.

I. H. Uhlig. (Chemical and Engineering News, 1946, vol. 23, Dec., pp. 3154-3158). A review of modern methods of metal protection outlining the principles of protection against corrosion is presented, and explanations are given of the manner in which the rate of corrosion is controlled by the application of several different methods, including the use of cathodic protection, metallic coatings, inorganic and organic coatings, adsorbed and reaction-product films, alteration of the environment, metal purification, and alloying.—J. P.

The Electrochemical Mechanism of Certain Corrosion Processes and Its Practical Implications.

J. R. Evans. (Corrosion and Material Protection, 1946, vol. 3, Aug.-Sept., pp. 15-18). After brief references to early work on corrosion and the oxidation of metals in dry air, the author discusses the mechanism of electro-chemical corrosion. Assuming that such corrosion is the result of electrical action in salt solutions, an explanation is given of the nature of passivity and of the fundamental principles of the use of inhibitors and metallic coatings.—C. O.

Steel Pipe Electroplated Inside for Corrosion Resistance.

S. G. Bart. (Corrosion and Material Protection, 1946, vol. 3, Oct.-Dec., pp. 8-10). The "Lectro-Clad" process for applying a corrosion-resistant surface to ordinary low-carbon steel pipe and tubing is described and illustrated by three photomicrographs showing the electrolytically-deposited film of nickel under various conditions of deposition, cold-reduction and welding. A feature of this process is the use of very high current density and this probably explains why the depressions in the steel base are more heavily coated than the high spots, and why adherence between nickel and steel is so perfect that the bond is not ruptured during heating or bending. The use of welding electrodes of Monel or 25/20 chromium-nickel steel in fabrication is illustrated by five photographs. Methods of fabricating flange joints and lap joints are also briefly mentioned and illustrated.—N. S.

Gas Holders "Paint Themselves".

(Corrosion and Material Protection, 1946, vol. 3, Oct.-Dec., pp. 11-12). A new method of painting water-sealed gas-holders with the finest finish and a substantial saving of cost is described. This is achieved by floating paint, having controlled viscosity and gravity characteristics, on the surface of the water in the holder cups. Paint recovery

devices are described and there are three photographic illustrations.—N. S.

Corrosion-Resistant Processing Equipment of Clad Steels for Chemical and Allied Industries.

E. C. Gosnell. (Corrosion, 1946, vol. 2, Dec., pp. 287, 306). The clad steels commercially available for plates and vessel covers are listed and a classification of clad steel is made into (a) homogeneously and (b) non-homogeneously bonded plates. The applications of the former are described and steps in its production illustrated by seven photographs. The factors influencing the design and proper selection of corrosion-resistant materials are enumerated and illustrated by twenty photographs of typical examples of processing equipment. Advice regarding the fabrication of this equipment is given and there are two diagrams illustrating the welding of clad steels. Examples are described under the headings of six chemical and allied industries in which war-time restrictions brought about a greater acceptance of clad steels and many new applications of them in processing equipment.—N. S.

Cathodic Protection.

C. H. McRaven. (Corrosion, 1946, vol. 2, Dec., pp. 320, 329). The principles underlying cathodic protection are reviewed and the theory of preventing corrosion by an application of the basic laws governing the flow of current is explained. The article deals with the protection of pipelines which are commonly subject to corrosion on small areas or patches because of differential aeration; the cathodic areas presenting an oxide surface to the soil, behave in effect as oxide electrodes, whilst the anodes, where there is insufficient oxygen to maintain an oxide film, are steel electrodes. This theme is elaborated and the problem of how to determine where an external applied current is sufficient to stop corrosion, is discussed. Making the necessary potential measurements with reference electrodes is also described. Mention is made of temporary "Ground-beds" and portable generating equipment, and consideration given to the effects of cathodic protection units upon other "foreign" pipe lines in the vicinity but not included in the protective scheme. The use of compensating cross-bonds having not too low a resistance is explained.—N. S.

Stress Corrosion Cracking of Mild Steel. Part VIII. Discussion of Contributed Criticism.

J. T. Waber and H. J. McDonald. (Corrosion and Material Protection, 1946, vol. 3, Oct.-Dec., pp. 13-20). Continuation of a series of papers (see Journ. I. and S. I., 1946, No. II, p. 62 A.

This paper is a collection of criticisms on the whole series invited by the authors, and it consists of comments from eight eminent contributors to which the authors reply in turn; it concludes with a summary of the principal results achieved by their investigations and a bibliography. The comments deal with aspects of the Dix theory, and with a newly-formulated "strain-accelerated decomposition" theory, to account for stress corrosion in the case of austenitic stainless steel, and for the general mechanism of crack propagation and strain-ageing. The rôle of nitrogen is also discussed by three of the contributors and the authors refer in their closing remarks to the importance of the "free nitrogen factor" in connection with strain-ageing.—N. S.

Progress in Corrosion and Heat Resisting Steels. L. Sanderson. (Engineering and Boiler House Review, 1946, vol. 61, Dec., pp. 199–200, 198). The compositions and properties of some of the new heat- and corrosion-resisting steels are summarized. Reference is made to the results of recent investigations into the atmospheric corrosion of stainless steel sheets, the decarburization of chromium steels, the strength and stability of passive films on stainless steels, external corrosion of tubes in boiler furnaces, the influence of heat-treatment and microstructure on creep, and the machining of stainless steel.—C. O.

The Activities of the Commission for Boiler Protection and Feed-Water Treatment (KKS) for the Chief Commanding Officer of the Admiralty. (British Intelligence Objectives Sub-Committee, 1946, Final Report No. 878: H.M. Stationery Office). This report is one of those issued on the corrosion of German naval boilers with special reference to the de-aeration of feed water. It deals comprehensively with the difficulties experienced with Wagner boilers and the steps taken to overcome them. The feed-water treatments which were evolved for operating the various types of boilers used in the German navy are also described in detail.—R. A. R.

Some Stress-Corrosion Studies on Austenitic Cast Irons. J. B. Urban, J. W. Bolton, and A. J. Smith. (Transactions of the American Society of Mechanical Engineers, 1946, vol. 68, Aug., pp. 633–636). Details are given of stress-corrosion tests performed upon four different austenitic cast irons and a grey cast iron. The test pieces were immersed in caustic soda at a temperature of 280° F. and loaded in tension to varying stresses. It was found that there is a limiting stress, in the region of 10,000 lb./sq. in., below which the effects

of stress-corrosion on austenitic irons are negligible or non-existent. Results for specimens loaded as beams bear out this finding.—C. O.

Coal Waggons. (Iron and Steel, 1946, vol. 19, Nov., p. 590). The desirability of using alloy steel instead of mild steel in the construction of coal waggons is discussed briefly. The arguments advanced, viz., economy, ease of repair, and robustness, are in favour of the use of mild steel. Illustrations are given to show that corrosion in steel waggons is caused by "coal water" and not to any great extent by climatic conditions.—C. O.

ANALYSIS

The Determination of Phosphorus in Austenitic Chromium-Nickel Steels. The Methods of Analysis Committee. (Journal of the Iron and Steel Institute, 1947, vol. 155, Mar., pp. 373–391). This work was carried out by the Phosphorus Panel of the Standard Methods of Analysis Sub-Committee of the Ingots Committee of the Iron and Steel Institute. The duties of this Sub-Committee have now been assumed by the Methods of Analysis Committee of the British Iron and Steel Research Association.

Following detailed investigations, a method has been formulated for the determination of phosphorus in highly alloyed steels containing titanium, vanadium, columbium, zirconium, tungsten, arsenic, and tin. The method is based on a perchloric-acid decomposition, which in the early part of the work had been found suitable for carbon and alloy steels not containing the foregoing elements. With this method, modifications have been incorporated to overcome the possible interference of these elements, the effects of which have been studied. Where possible, the selected modifications have been those having the widest application, so that undue complication of the basic method has been avoided. The important features of the recommended method are:

(i) A high nitric-acid concentration to prevent the inhibiting effects of titanium and vanadium, and to prevent formation of insoluble zirconium phosphate.

(ii) The recovery of occluded phosphorus in the presence of tungsten, columbium, and zirconium by precipitation of magnesium ammonium phosphate from ammoniacal solution, assisted by the addition of arsenate.

(iii) Elimination of arsenic and tin by treatment with hydrobromic acid.

Identification of Ferro-Alloys. T. R. Cunningham. (Blast Furnace and Steel Plant, 1946, vol. 34, Aug., pp. 1003–1004). Rapid and fairly

simple methods of identifying ferro-alloys are described. These include the following determinations: (1) The approximate amount of carbon in ferromanganese and ferrochromium; (2) the approximate amount of silicon in ferrosilicon; (3) whether an alloy is silicomanganese or ferro-silicon; and (4) the identification of ferro-vanadium and ferroboration.—R. A. R.

Study of Millin Technique for Determination of Carbon and Hydrogen in Coal. R. J. Grace and A. W. Gauger. (Industrial and Engineering Chemistry, Analytical Edition, 1946, vol. 18, Sept. 21, pp. 563-565). The apparatus and procedure used in a study of the Millin technique for the determination of carbon and hydrogen in coal are described. Tests were made with pure organic samples, and these showed that the technique gives satisfactory results for many other combustible substances in addition to bituminous coal and anthracite. The maximum differences in duplicate analyses were 0.28% for carbon and 0.05% for hydrogen.—c. o.

MISCELLANEOUS

Metallurgical Education. D. Hanson. (Institute of Metals: Metal Industry, 1947, vol. 70, Jan. 10, pp. 25-28; Jan 17, pp. 47-48). A satisfactory course in scientific metallurgy today must be built on a foundation of chemistry, physics and mathematics of a standard much higher than those of the Higher Certificate Examination or the University Intermediate or First Examination. It should also include an adequate treatment of those particular develop-

ments in science which, so far as can be judged at the present time, are likely to extend our knowledge and hence our practice in succeeding decades.—R. E.

Whither Metallurgy. J. W. Jenkin. (Sheffield Metallurgical Association: Metallurgia, 1946, vol. 35, Nov., pp. 41-46). The development of metallurgy through the centuries is traced on broad lines, and some modern trends in research and the training of metallurgists are indicated.—c. o.

Battelle Memorial Institute Conducts Extensive Research Related to Steel Plant Operations. (Blast Furnace and Steel Plant, 1946, vol. 34, Oct., pp. 1271-1276). A short summary is given of the research work in progress at the Battelle Memorial Institute on the subjects of ore-dressing, steel processing, fuel utilization, refractories, and electrochemistry.—c. o.

How to Use Welding Equipment to Thaw Frozen Water Pipes. R. F. Wyer. (Iron and Steel Engineer, 1946, vol. 23, Nov., pp. 102-103). Ways in which electric-welding equipment can be adapted to thaw ice in water pipes by resistance heating of the metal walls are explained.—c. o.

Salvaging and Reclaiming Scrap. (Steel, 1946, vol. 119, Dec. 16, pp. 90, 142-145). The methods adopted by an American railway company for salvaging scrap metals are described. All the worn out or damaged material of the system is collected in one plant for segregation; as much as possible is reconditioned for further use, and the remainder is sold for remelting.—c. o.

BOOK REVIEWS

COWDREY, I. H. and R. G. ADAMS. "*Materials Testing. Theory and Practice.*" Second ed. rev. and enl. 8vo, pp. vii + 156. Illustrated. New York, 1944: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd. (Price 12s.).

In this new edition, the authors have included additional material, and some new illustrations and tables. An entirely new illustrated chapter on photo-elastic analysis has been added, with special reference to the field of application and the use of the polariscope.

MCCASLIN, H. J. "*Wood Patternmaking.*" Fourth ed. Sm. 8vo, pp. xxviii + 366. Illustrated. New York and London, 1946: McGraw-Hill Book Co., Inc. (Price 13s.).

In this new edition the text has been enlarged so as to present a wider range of present-day pattern-shop practice. As in earlier editions, the text is divided

into two parts—Part I on bench work and Part II on lathe work.

NEWBOULT, H. O. "*Analytical Method in Dynamics.*" 8vo, pp. 81. Oxford, 1946: Clarendon Press. (Price 7s. 6d.).

This book treats various topics in dynamics in ways differing from those used in most of the current text-books. They are meant to be used as a supplement to one of these books and not as a substitute. Only worked examples are included, as there are excellent collections of examples in the text-books in ordinary use.

TREWMAN, H. F. "*Mechanical Inspection.*" 8vo, pp. xii + 164. Illustrated. London, 1946: Sir Isaac Pitman and Sons, Ltd. (Price 15s.).

This is a survey of the underlying principles and practical aspects of mechanical inspection with special

reference to precision engineering. The subjects dealt with are: purposes of inspection, general factors affecting inspection, accuracy, definitions of terms, standards of measurement, various general-purpose measuring instruments, measuring length and flatness, measuring diameter, measuring angles, and measuring screw threads. There is also a chapter on American measuring instruments.

WOOD, V. N. "*Metallurgical Materials, Alloys and Manufacturing Processes*." With a Foreword by J. W. Gardom. 8vo, pp. xi + 340. Illustrated. London, 1946: Chapman and Hall, Ltd. (Price 25s.).

It is now recognized that engineers should have a general knowledge of certain aspects of metallurgy, and this is shown by the fact that metallurgy is included in courses designed for those seeking a recognized qualification such as a degree or a National Certificate in Engineering.

The knowledge of metallurgy required by engineers is only a part of the subject, and, in the same way, the knowledge of engineering required by metallurgists is relatively elementary in character. It accordingly follows that a book on metallurgy suited to the requirements of engineering students would be totally inadequate for those hoping to make metallurgy their career.

It would appear that the author of this book has attempted, but without much success, to meet in one volume of 340 pages, the requirements of both engineers and metallurgists.

The first chapter is devoted to the manufacture of iron and steel, a subject which has been dealt with in an elementary manner, and this is followed by three chapters entitled "Mechanical Testing," "Physical Examination of Metals," and "Industrial Control and Measurement of Temperature." These four chapters constitute more than one-third of the book.

The five chapters which follow also occupy more than one-third of the volume, and deal with carbon and alloy steels, cast iron, malleable cast iron and the mechanical and thermal treatment of steel, respectively.

Although it is stated in the introduction to Chapter 10—"Non-Ferrous Metals and Alloys"—that "The non-ferrous branch of metallurgy covers a wide range of metals and alloys, with a very comprehensive range of properties," the data in regard to these metals and alloys is confined to about 40 pages.

The book is too ambitious in certain sections, as is shown by the inclusion of the subject "The Electron Microscope," but, on the other hand, it lacks information of practical value, such as tests for hot- and cold-working properties, as well as recognized acceptance tests. It contains 33 plates with numerous photomicrographs, which have been well selected and satisfactorily reproduced. Some of the pictorial illustrations, however, are blurred and indistinct, and accordingly of little use.

G. PATCHIN

WRAZEJ, J. W. "*Metale w Przemysle*" (Biblioteczka Rzemieślnicza Lwowskiego Towarzystwa Kursów Technicznych. Tom 2). Sm. 8vo, pp. 160. Illustrated. London, 1946: Polish Technical Publishing Trust.

This small Polish work, which is a new edition of a previous work by the author, edited by the Polish Ministry of Education, is intended for students in both the lower grade and higher grade technical schools. Two sizes of type are used in its production: large type for information of use to lower-grade students and small type which presents knowledge for those of the higher grade, such as mechanics, engineers, etc. Each stage in the manufacture of iron and steel from the ore to the final product, including foundry practice, is illustrated.

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BATCHER, R. and W. MOULIC. "*The Electronic Control Handbook*." Pp. vii + 344. New York: Caldwell-Clements Inc. (Price \$4.50).

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FEIGL, F. "*Qualitative Analysis by Spot Tests*." Third Edition. Translated by R. E. Cooper. Pp. 574.

New York: Elsevier Publishing Co., Inc. (Price \$8.00).

HARRISON, H. L. "*Examination, Boring and Valuation of Alluvial and Kindred Ore Deposits*." London: Mining Publications Ltd. (Price 30s.).

JACOBSON, C. A. "*Encyclopedia of Chemical Reactions*." 8vo, pp. 804. New York: 1946: Reinhold Corporation. (Price \$10.00).

METAL TREATING INSTITUTE. "*Manual for Heat Treating Services*." New York: The Institute. (Price \$4.00).

MUDD, O. C. "*Control of Pipe Line Corrosion*." Houston, Texas: National Association of Corrosion Engineers. (Price \$1.25).

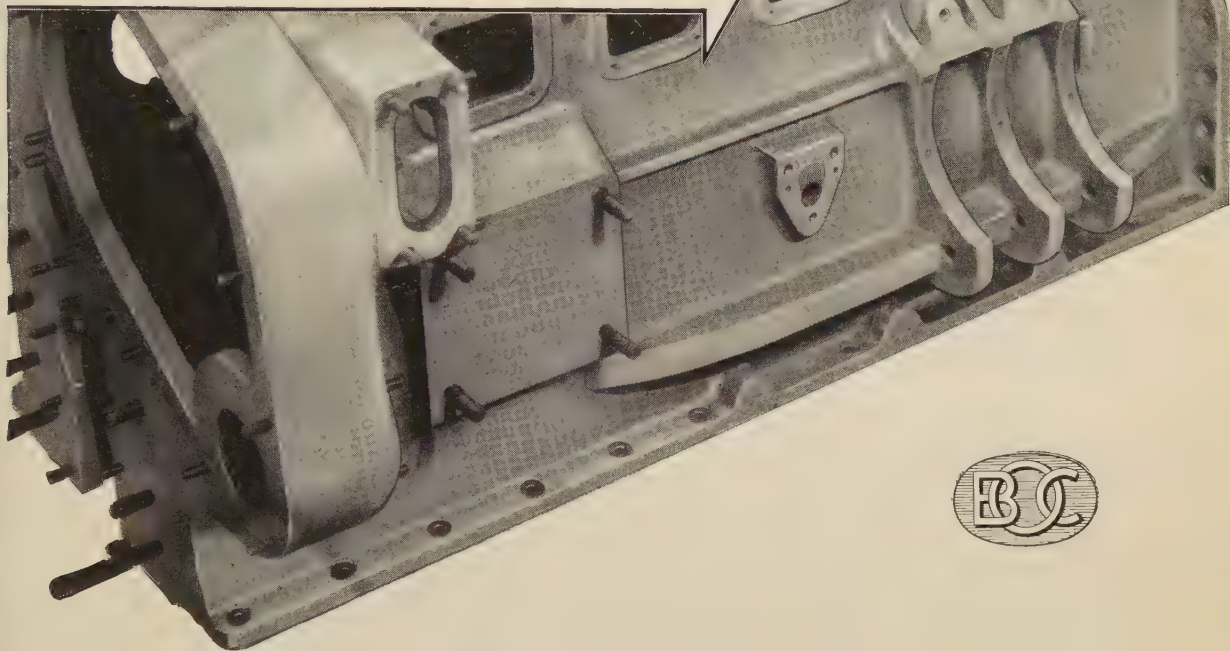
STEINER, K. "*Fuels and Fuel Burners*." New York: McGraw-Hill Book Co., Inc.; London: McGraw-Hill Publishing Co., Ltd. (Price 22s. 6d.).

VIVIAN, A. C. "*Essential Metallurgy for Engineers*." Second edition. 8vo, pp. 156. London, 1946: Sir Isaac Pitman and Sons, Ltd. (Price 8s. 6d.).

WILLIAMS, J. N. "*Steam Generation*." Pp. 372. London: Evan Brothers, Ltd. (Price 25s.).

WORK STOPS..

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—THANKS TO OXY-ACETYLENE WELDING!**

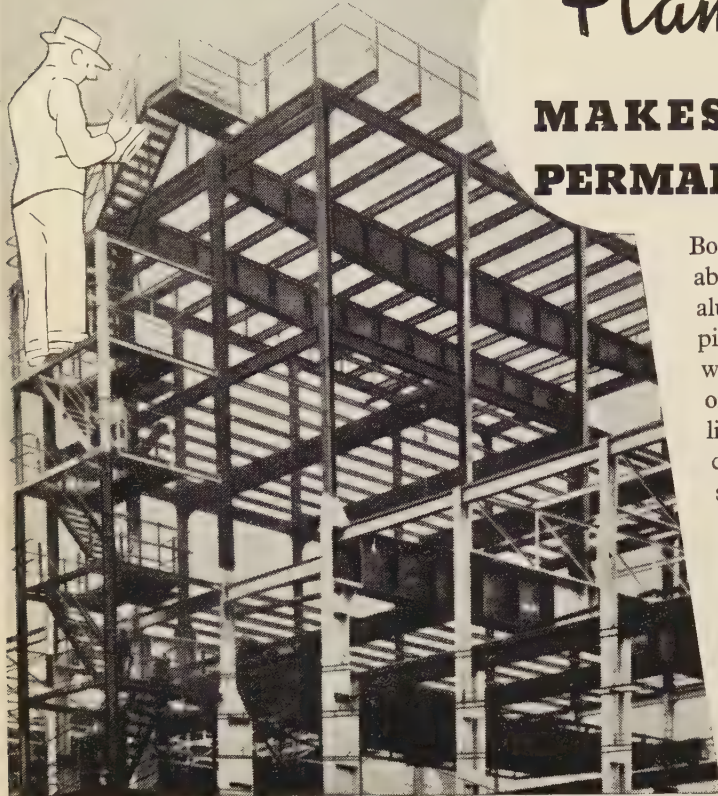


In a world of difficulties, delays and unobtainable replacements, a speedy, efficient repair service is the only way to keep production flowing. Few are the repairs which cannot be tackled by the manifold oxy-acetylene processes such as cutting, welding, brazing and gouging and their many applications developed by The British Oxygen Company.

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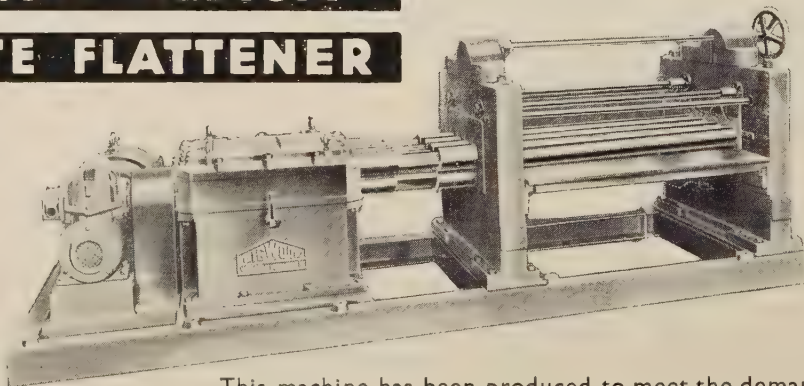
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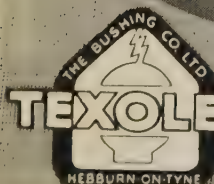
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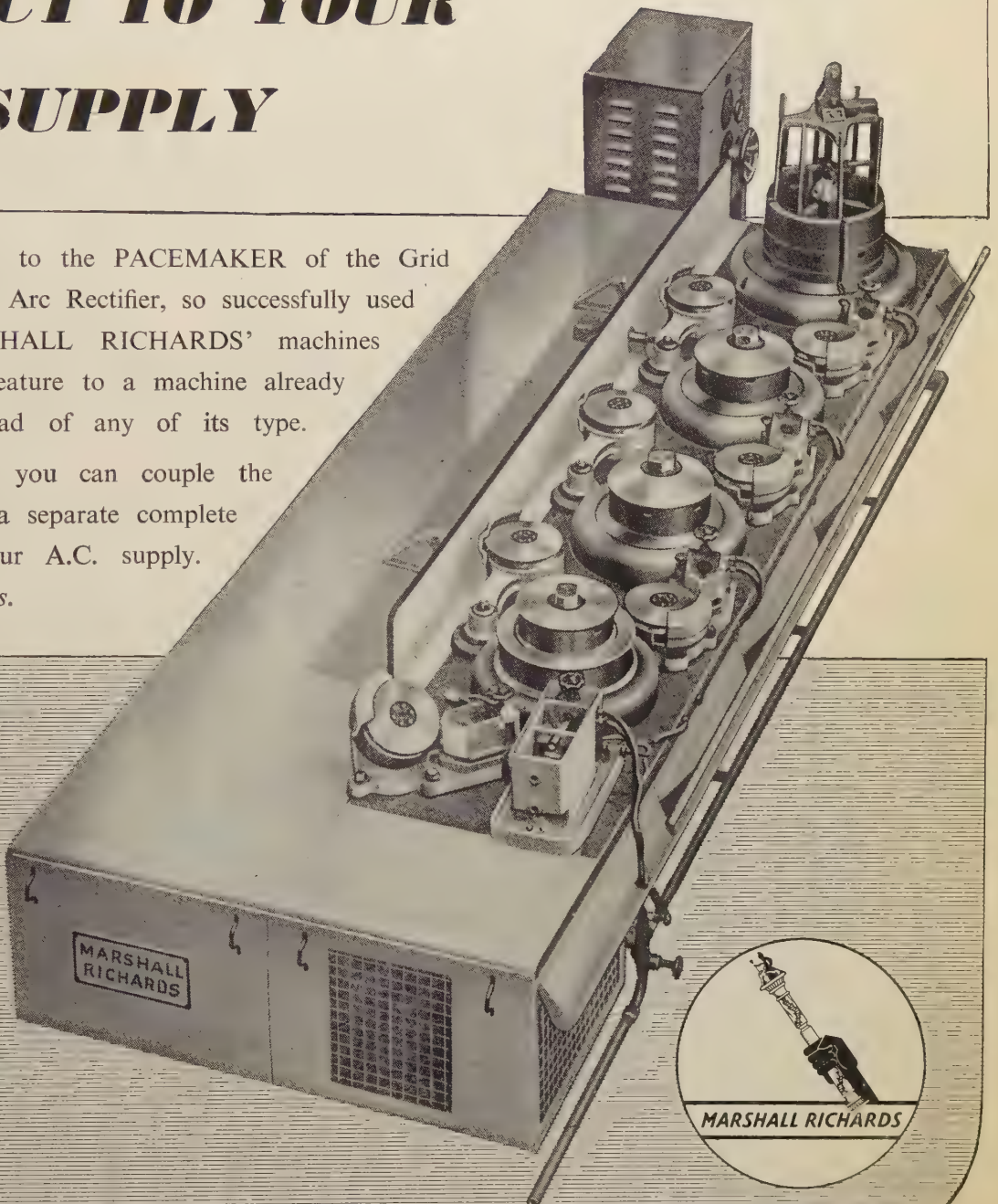
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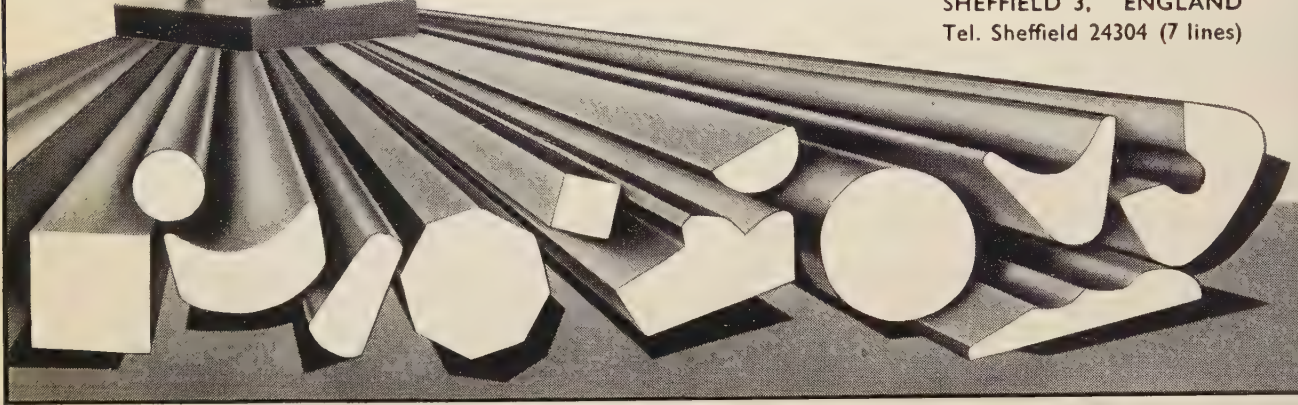
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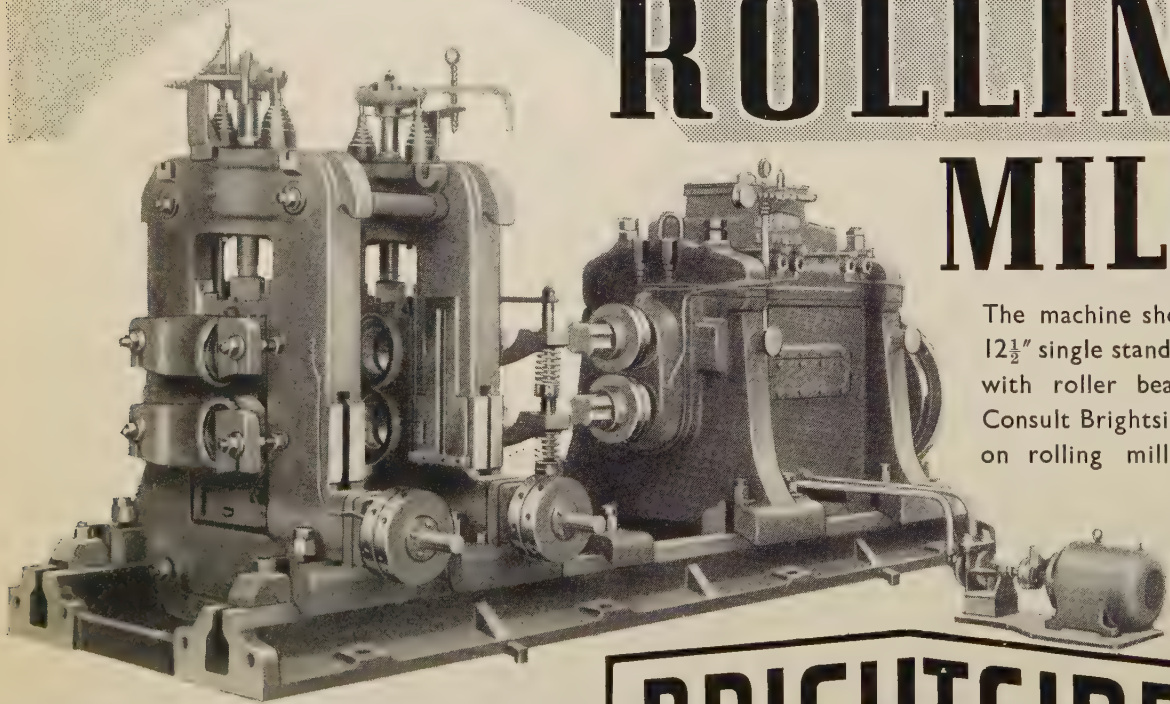
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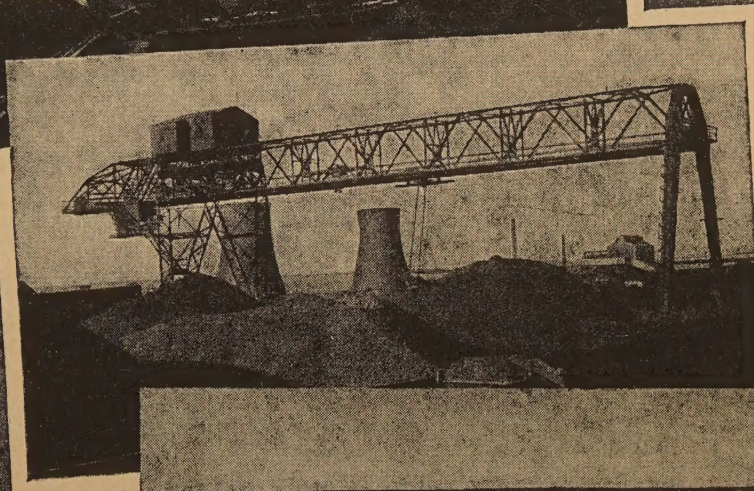
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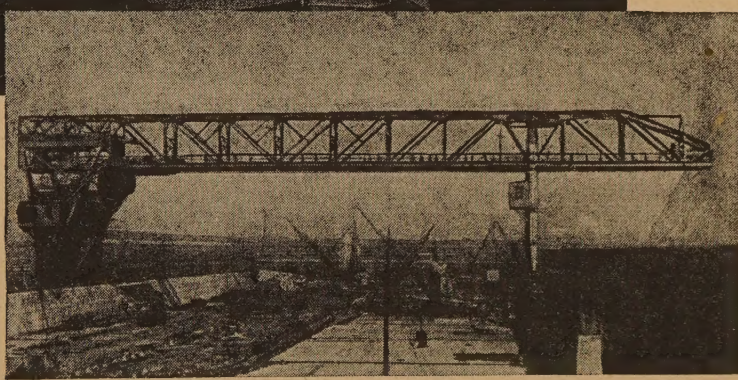
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